The Society for engineering in agricultural, food, and biological systems

An ASAE Meeting Presentation

Paper Number: 052180

Sensor-Based Control of Irrigation in Bermudagrass

Bernard Cardenas-Lailhacar
Agricultural and Biological Engineering Dept., University of Florida, PO Box 110570 Gainesville, FL 32611, bernardc@ufl.edu

Michael D. Dukes
Agricultural and Biological Engineering Dept., University of Florida, PO Box 110570 Gainesville, FL 32611, mddukes@ufl.edu

Grady L. Miller
Environmental Horticulture Dept., University of Florida, PO Box 110670 Gainesville, FL 36211-0670, gmiller@mail.ifas.ufl.edu

Written for presentation at the
2005 ASAE Annual International Meeting
Sponsored by ASAE
Tampa Convention Center
Tampa, Florida
17 - 20 July 2005

Abstract. *Irrigation water use represents a substantial opportunity for residential water savings. Automation of irrigation systems, based on soil moisture sensors (SMSs), has the potential to provide maximum water use efficiency by maintaining soil moisture at optimum levels. The objectives of this experiment were to quantify differences in irrigation water use and turf quality between: 1) a SMS-based irrigation system compared to a completely time-based scheduling, 2) different commercial irrigation SMSs, and 3) a completely time-based scheduling system with or without a rain sensor. The experimental area consists of common bermudagrass (*Cynodon dactylon L.*), located in Gainesville, Florida. Four quarter-circle pop-up sprinklers, in a square with 3.66 m sides, irrigated each of 64 plots, distributed in a completely randomized design. Treatments consisted of irrigating one, two, or seven days a week. Each of these schedules compared four different commercial SMSs brands. These SMSs may interrupt scheduled irrigation cycles, depending on the soil moisture status. Other treatments compared plots with or without a rain sensor. A non-irrigated treatment was also implemented. No significant differences in turfgrass quality among treatments were detected, which was evidenced by good quality in non-irrigated plots. Treatment without-rain-sensor used 45%*

more water than the with-rain-sensor treatment. Not all SMSs tested performed the same. Sensors from brand A recorded irrigation water savings ranging from 59% to 88%, brand B from 73% to 82%, and brand D from 46% to 81%, depending on the scheduled irrigation frequency. Brand C showed water savings only within a 1-day/week frequency.

Keywords. Soil moisture sensor, rain sensor, automation, irrigation scheduling, residential irrigation, water use, turfgrass, bermudagrass, turf quality, landscape.

Introduction

Florida receives an average of around 1400 mm of rainfall a year. Unlike most areas dependent on irrigation, annual rainfall in Florida typically exceeds evapotranspiration. Nevertheless, irrigation is required because total annual rainfall for Florida typically varies both geographically and temporally (USDA, 1981; Carriker, 2000). Such rainfall variation has a direct impact on surface water and groundwater supplies. Lack of rainfall for even a few days causes depletion of moisture in Florida's predominately sandy soils, along with reduction of stream flow and groundwater recharge (Carriker, 2000; National Research Council, 1996).

Florida has the second largest withdrawal of groundwater for public supply in the United States (Solley et al., 1998). Groundwater was the source of more than 88 % of the water withdrawn for public supply in 1990 (Carriker, 2000). In 1995, nearly 93% of population in Florida used groundwater as a drinking water source (Solley et al., 1998). Water withdrawals for public supply in Florida have increased rapidly, from 600,000 m^3/day in 1950 to 7.3 million m^3/day in 1990 (Carriker, 2000). The population served by public-supply systems increased from 5.42 million in 1970 to 11.23 million in 1990 (Marella, 1992).

Florida has a fast-growing population with a net inflow of nearly 875 people a day, and ranks as the second largest net gain in the nation. The current population of 17 million is projected to exceed 20 million people by 2020. By 2025 it is projected to be the 3rd most populous state in the nation (USCB, 2004). As urban populations swell, pressures on limited supplies of clean water will increase.

The indoor water use per person in U.S. is relatively constant across all geographic and social lines. Depending on an area's climate, residential outdoor water use can account for 22% to 67% of total annual water use (Mayer et al., 1999). The primary use of residential outdoor water is irrigation. In Florida, the dry and warm spring and fall weather, the sporadic large rain events in the summer, coupled with low water holding capacity of the soil, make irrigation indispensable for the high quality landscapes desired by homeowners (Baum et al., 2003; National Research Council, 1996). Recent studies in the U.S. indicate that, on average, 58% of potable water is used for landscape irrigation. In the Central Florida Ridge, this average is as high as 71% (Baum et al., 2003). Consequently, proper irrigation water use clearly represents a substantial opportunity for residential water savings.

Furthermore, residential water use research, carried out by Mayer et al. (1999), found that homeowners with standard landscape used 77 mm per month, in average, for irrigation purposes in U.S. However, in Central Florida, Baum (2005) found that typical homeowners used an average of 146 mm per month. Homeowners using irrigation timers (time clock controllers), set to seasonal plant water requirements, used 16% less irrigation water on average than non-timer users. Typically, homeowners irrigated too much in the late fall and winter, often due to lack of knowledge about the necessary length of irrigation run times for specific seasons and/or plant material (Baum, 2005). Therefore, opportunities that result in better irrigation scheduling by homeowners may lead to substantial savings in irrigation water use.

Irrigation time clocks have been available for many years in the form of mechanical and electromechanical irrigation timers. These devices have evolved into electronic systems that allow accurate control of water, while responding to environmental changes and plant demands (Zazueta et al., 2002). The concept of hooking up soil moisture sensors (SMSs) to determine irrigation needs, and to automate irrigation systems, has also moved forward. Newer methods that measure the electrical properties of the soil water medium and then estimate soil water content have recently become commercially available.

A wide range of applications to automatically control irrigation events has been investigated in sandy soils. In Florida, switching tensiometers have been studied for agricultural production (Clark et al., 1994; Smajstrla and Locascio, 1994; Muñoz-Carpena et al., 2003; Smajstrla and Koo, 1986), and for maintaining bermudagrass turf (Augustin and Snyder, 1984). However, these investigations suggest that tensiometers require calibration and frequent maintenance, up to twice per week. Consequently, the adoption of this technology will not lead to automatically controlled irrigation since it will not eliminate human interaction in irrigation management.

Other types of sensors can be adapted to automate irrigation based on soil moisture status. Solid state sensors such as capacitance-based sensors, Time Domain Reflectometry (TDR) probes, and granular matrix sensors (GMS) have become available on the market. Dukes and Scholberg (2004) and Dukes et al. (2003), found 11% and 50% in water savings, respectively, using TDR probes. GMSs have also been used to automatically irrigate agricultural products (Muñoz-Carpena et al., 2003; Shock et al., 2002) and, as with other solid state sensors, do not require as much maintenance as tensiometers. Although both TDR and GMS, as well as similar types of sensors, have been successfully used in agriculture, they have found limited use in residential landscape irrigation (Qualls et al., 2001).

The objectives of this experiment were to quantify differences in irrigation water use and turf quality between: 1) a SMS-based irrigation system compared to a completely time-based scheduling, 2) different commercial irrigation SMSs, and c) a completely time-based scheduling system with or without a rain sensor.

Materials and Methods

The experimental area is located at the Agricultural and Biological Department facilities, University of Florida, Gainesville, Florida; on Arredondo fine sand (loamy, siliceous, semiactive, hyperthermic Grossarenic Paleudults) (USDA-NRCS, 2003), covered with common bermudagrass (*Cynodon dactylon L.*). All plots were mowed twice weekly at a height of 5.5 cm. Chemicals were applied as needed to control weeds and pests. Nutrient applications were made using Ammonium Sulfate, at a rate of one pound of nitrogen per thousand square feet (49 kg of N per ha), on April and May, before the beginning of the experiment. Then, a granulated and controlled-release fertilizer (Polyon, PTI, Sylacauga, AL) was applied at a rate of 3.7 #N/1000 sq ft (180 kg N/ha), in July.

Treatments

Four SMSs commercially available were selected for evaluation: *Acclima Digital TDT* (Acclima Inc., Meridian, ID), *Watermark 200SS-5* (Irrometer Company, Inc., Riverside, CA), *Rain Bird MS-100* (Rain Bird International, Inc., Glendora, CA), and *Water Watcher DPS-100* (WaterWatcher, Inc., Logan, UT). Specific brands are not identified in this document, rather they were randomly assigned “A”, “B”, “C”, and “D” designations.

All four sensors were tested (Table 1) with three watering frequencies: one, two, and seven days per week (1d/w, 2d/w and 7d/w, respectively). The 1d/w and 2d/w watering frequencies represent typical existing conditions, due to watering restrictions imposed in Florida (Florida Department of Environmental Protection, 2002; SJRWMD, 2004). These SMSs may interrupt scheduled time clock irrigation cycles, depending on the soil moisture status.

These SMS-based treatments were compared to a 2d/w time-based irrigation schedule, set to replace the full amount of historical evapotranspiration (ET), and to another treatment set to replace 60% of historical ET (treatments 2-WRS and 2-DWRS, respectively).

These two treatments (2-WRS and 2-DWRS) were connected to a rain sensor shut-off device (*Mini-click II*, Hunter Industries, Inc., San Marcos, CA), to simulate requirements imposed on homeowners by Florida Statutes (Section 373.62). This rain sensor was set at 6.4 mm (1/4 of an inch). A 2d/w without-rain-sensor treatment (2-WORS) was also included, in order to simulate homeowner irrigation systems with a non-functional rain sensor. Finally, a non-irrigated treatment (0-NI) was also implemented.

All the treatments were programmed to receive the same amount of water, except for 0-NI and 2-DWRS treatments. The irrigation cycles were adjusted monthly, and the volume was set following the historical ET-based irrigation schedule recommended by Dukes and Haman (2002) for the area where this experiment was carried out. These cycles were programmed on two *ESP-6Si*, and three *ESP-4Si* timers (Rain Bird International, Inc., Glendora, CA). They were set to start between 0100 and 0600 h, with the purpose of diminishing wind drift and decreasing evaporation. Once the bermudagrass went dormant, irrigation was discontinued.

All experimental treatments were replicated four times in a completely randomized design for a total of 64 plots. Each turfgrass plot was 3.66 m X 3.66 m (12 ft X 12 ft) and was sprinkler irrigated by residential-type four-quarter circle pop-up spray heads (Hunter 12A, Hunter Industries, Inc., San Marcos, CA).

During initial irrigation-system uniformity testing on the plots, the driest plots were identified for placement of the SMSs, according to recommendations by the manufacturers. The soil moisture sensor that controlled a particular treatment was buried in the center of one of these driest plots, thereby controlling all the four replicates. The sensors were positioned in the soil following the manufacturers' recommendations, in the top 7-10 cm of the soil, where most of the roots were present.

Data collection

Pulse-type positive displacement flowmeters (PSMT 20mm x 190mm, Amco Water Metering Systems, Inc., Ocala, FL) were connected to a CR 10X datalogger (Campbell Scientific, Logan, UT), used to continually measure irrigation frequency and volume applied to each plot. In addition, meters were read manually each week.

Weather data were collected by an automated weather station (Campbell Scientific, Logan, UT), located within 1 m of the experimental site. Measurements made every fifteen 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 (Skogley and Sawyer, 1992). A rating of 5 was considered to be the minimum acceptable turf quality for a homeowner. Ratings were conducted at the beginning, middle, and end of the study, before turf dormancy (July, October and December).

Data presented in this publication represent the first season of an ongoing experiment, and were obtained from 20 July through 14 December of 2004, when the turfgrass went dormant due to cool temperatures. However, a tropical storm and two hurricanes - Frances and Jeanne -

passed over the research field area during the experiment time (Figure 2) and, in order to avoid possible damage to the equipment, power was turned off and no data were collected from 26 September through 30 September of 2004.

Data analysis was performed using the general linear model (GLM) function of the Statistical Analysis System software (SAS, 2000). Analysis of variance was used to determine treatment differences and Duncan's Multiple Range Test was used to identify mean differences. All significance was at the 95% confidence interval.

Results and Discussion

Water use volume

Treatment 2-WRS was established to simulate Floridian homeowners with relatively well-managed automatic irrigation systems; therefore, it was employed as a control treatment. During the experiment, this treatment accounted for 481 mm of water, or an equivalent of 98 mm/month (Table 2). A recent study, carried out in Central Florida by Baum (2005), found that homeowners with well-managed automatic irrigation systems applied 116mm/month on average. Therefore, the comparisons in this paper can be considered conservative and differences with actual homeowners could be larger.

The very well-managed homeowner profile, imitated by the 2-DWRS treatment, applied 310 mm, or 64% of 2-WRS, close to the 60% desired. The treatment simulating a system with an absent or non-functional rain sensor (2-WORS) accounted for 696 mm. This is 45% more water than the functional one (2-WRS), showing that the presence of a rain sensor as well as its maintenance is significant for irrigation water savings.

Although all these time-based treatments (2-WRS, 2-WORS, and 2-DWRS) were significantly different from each other (Table 2), 2-DWRS showed no statistical difference from the average of the SMS-based treatments. However, this result could lead to the false impression that merely adjusting the timers to replace 60% of the historical ET would achieve the SMS-based treatments savings at a 2d/w-frequency. As seen on Table 3, there were great differences among the tested SMSs at 2d/w-frequency, showing that these can use from 52% more water, to 72% less water than the 2-DWRS treatment.

No rain sensor was hooked up to SMS-based treatments. However, some SMSs overrode scheduled cycles after a rain, avoiding unnecessary irrigation. This is clearly shown in Table 3, where some SMSs led to water savings under the same irrigation frequency as the completely time-based treatments. These savings were over 80% in cases where the rain sensor was functional (2-B and 2-D vs. 2-WRS), or more than 86%, if the rain sensor was not operating (2-B and 2-D vs. 2-WORS). Even compared to 2-DWRS, treatments 2-B and 2-D applied 70% less irrigation water.

The averages of the SMS-based frequencies (Table 3) show that there is not a large difference among them, when compared across irrigation frequency per week (188, 212 and 218 mm; for one, two or seven days a week, respectively). In addition, they show that all of them used less than half of the water used by 2-WRS (481 mm). However, the range of water applied within these three different scheduled frequencies varied widely**:** from 95 to 318 mm for the 1d/w, 87 to 470 mm for the 2d/w, and 57 to 471 mm for 7d/w treatments. Therefore, the averages do not represent the wide variation among the different SMSs evaluated.

Soil Moisture Sensors comparison

As an overall comparison (Figure 1), sensors from brand C used the highest amount of water, 420 mm on average, and were statistically different from those of brand D, which used 188 mm. Sensors from brands A and B had the best performance, showing the lowest water use rate, with 116 and 100 mm, respectively; and showed no statistical difference between them, but were lower than brands C and D.

Brand C showed 13% of water savings on average compared to the control treatment. However, in the three frequencies tested, brand C accounted for the highest values of water use (Figure 1). Brand C performed best at 1d/w frequency, where the savings were around a third compared to 2-WRS (Table 4). Nevertheless, at 2- and 7-d/w-frequencies, brand C showed no difference from 2-WRS. This could indicate that the time needed for brand C to “sense” the changes in the soil water content, after a rainfall or an irrigation cycle, is not adequate for frequencies higher than once-per-week scheduling and/or for sandy soils, such as the one where this experiment was carried out.

The other brands exhibited statistical differences in all the irrigation frequencies when compared to 2-WRS. Sensors from brand A recorded irrigation water savings ranging from 59% to 88%, brand B from 73% to 82%, and brand D ranged from 46% to 81% (Table 4).

These results clearly demonstrate that the use of SMSs, along with the traditional timers in residential irrigation systems, can lead to important water savings. However, the correct choice of the SMS, and its technology to measure or “sense” the soil water status, is of great consequence. The benefit-cost relationship should also be considered, since the commercial cost of these devices varies greatly, from approximately US$ 75 to more than US$400 per unit.

Complete automation of a residential irrigation system, based on SMSs, could be achieved programming the timer to run every day as a scheduling strategy. Then, the SMSs will allow the system to irrigate only when it is actually required, and override it when the sensed water content is over a pre-set threshold. In this experiment, two of the SMS-based treatments programmed to run 7d/w used the smallest amount of water (Table 4). Water savings of 88% and 82% were recorded for 7-A and 7-B, respectively, compared to 2-WRS. These SMS-based results, reinforced by other experiments using this technology, open the possibility of redefining the best management practices for residential irrigation, and for review and further discussion of the state’s watering restrictions as well.

In addition, the timers were set monthly to replace the historical ET-based irrigation schedule recommended by Dukes and Haman (2002). But Floridian homeowners do not usually adjust their irrigation time clock frequently (Baum et al., 2003; Augustin and Snyder, 1984). Therefore, differences in water use volume could have been greater if the timers were set with few or no scheduling variation among months or seasons.

Turfgrass quality

No differences in the turfgrass quality (including non-irrigated plots) were found through the different seasons. This could be explained in part by the species itself. Bermudagrass is known as a more drought-tolerant grass compared to the pervasive St. Augustinegrass found in North-Central Florida (Trenholm, 2000). In addition, the meteorological conditions were favorable, until the first frost arose and the bermudagrass went dormant. Moreover, a high frequency and large amount of rainfall might have contributed to the fact that differences in turfgrass quality were not detected (Figure 2). Based on the turfgrass quality measurements, irrigation was not required for acceptable turfgrass quality during the time period of this study. However, most homeowners would have irrigation programmed on their time clock, indicating that this technology could save substantial irrigation water if implemented.

Conclusions

- No significant differences in turfgrass quality among treatments were detected, which was evidenced by good quality in non-irrigated plots.
- The without-rain-sensor treatment used 45% more water than the treatment with a functional one, showing the importance not only for the presence but also for the need of a well-maintained rain shut-off device in automated irrigation systems.
- Soil moisture sensors represent an important technology to take into consideration, because of the water savings that they can accomplish, together with an acceptable turfgrass performance.
- Not all SMSs tested performed the same. Sensors from brand A recorded irrigation water savings ranging from 59% to 88%, brand B from 73% to 82%, and brand D from 46% to 81%, depending on the scheduled irrigation frequency. Brand C showed statistical differences on water savings only within a 1-day/week frequency.
- The correct choice of a SMS should take into consideration features like its technology, response-time, irrigation scheduling strategy, and cost, among other aspects.
- The control treatment was fairly well-managed and conservative, compared to homeowners' actual operation practices, so that "real" water savings on residential landscapes could be even greater.
- This technology should be tested under real homeowner conditions in order to validate these results.
- These SMS-based results, reinforced by other experiments using this technology, open the possibility of redefining the best management practices for residential irrigation, and for review and further discussion of the state's watering restrictions as well.

Acknowledgements

The authors wish to thank Engineer Larry Miller, Senior Engineering Technician Danny Burch, and students Mary Shedd, Stephen Hanks, Clay Coarsey, Brent Addison, and Clay Breazeale for their assistance on this project. This research was supported by the Pinellas-Anclotte Basin Board of the Southwest Water Management District, the Florida Nursery and Landscape Growers Association, and the Florida Agricultural Experiment Station and approved for publication as Journal Series No. N-02658.

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Table 1. Description of the experimental treatments.

Treatment	Irrigation Frequency (days/week)	Soil Moisture Sensor Brand or Treatment Description
SMS-Based		
1-A	1	Brand A
1-B	1	Brand B
1-C	1	Brand C
1-D	1	Brand D
2-A	2	Brand A
2-B	2	Brand B
2-C	2	Brand C
2-D	2	Brand D
7-A	7	Brand A
7-B	7	Brand B
7-C	7	Brand C
7-D	7	Brand D
Time-Based		
2-WRS	2	With rain sensor
2-WORS	2	Without rain sensor
2-DWRS	2	60% Deficit historical ET, with rain sensor
0-NI	0	No irrigation

SMS= Soil moisture sensor

Table 2. Total irrigation depth applied to Time-based treatments and to Soil Moisture Sensor-based treatments' average, and water savings compared to 2-WRS.

Treatment	TOTAL (mm)+	Savings compared to 2-WRS (%)
2-WORS	696 ***a***	-45
2-WRS	481 ***b***	0
2-DWRS	310 ***c***	36
SMS Avg	206 ***c***	57

+Different letters within column depict statistically different means at P <0.05
See Table 1 for treatments abbreviations. SMS= Soil moisture sensor; Avg= Average

Table 3. Total irrigation depth applied by treatment.

Treatment	TOTAL (mm)
SMS-Based	
1-A	95
1-B	128
1-C	318
1-D	209
1-Avg	**188**
2-A	196
2-B	87
2-C	470
2-D	94
2-Avg	**212**
7-A	57
7-B	85
7-C	471
7-D	261
7-Avg	**218**
SMS-Avg	**206**
Time-Based	
2-WRS	481
2-WORS	696
2-DWRS	310
0-NI	0

See Table 1 for treatments abbreviations. SMS= Soil moisture sensor; Avg= Average

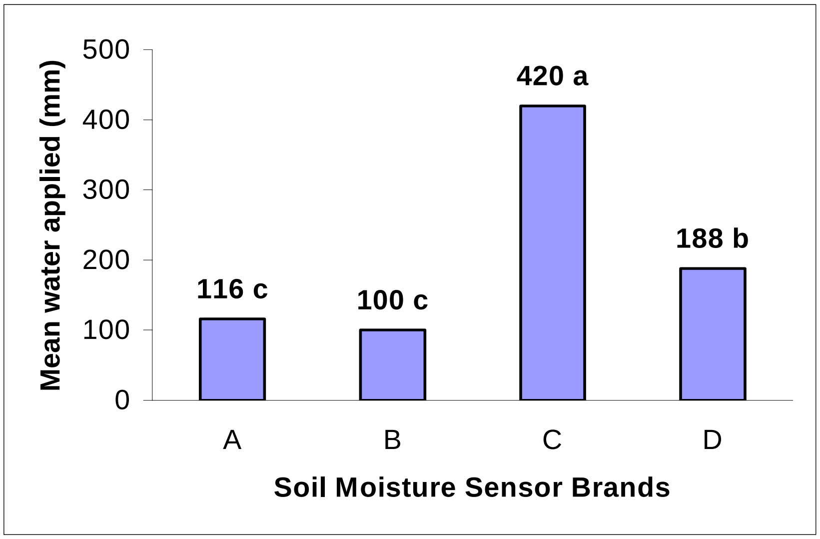
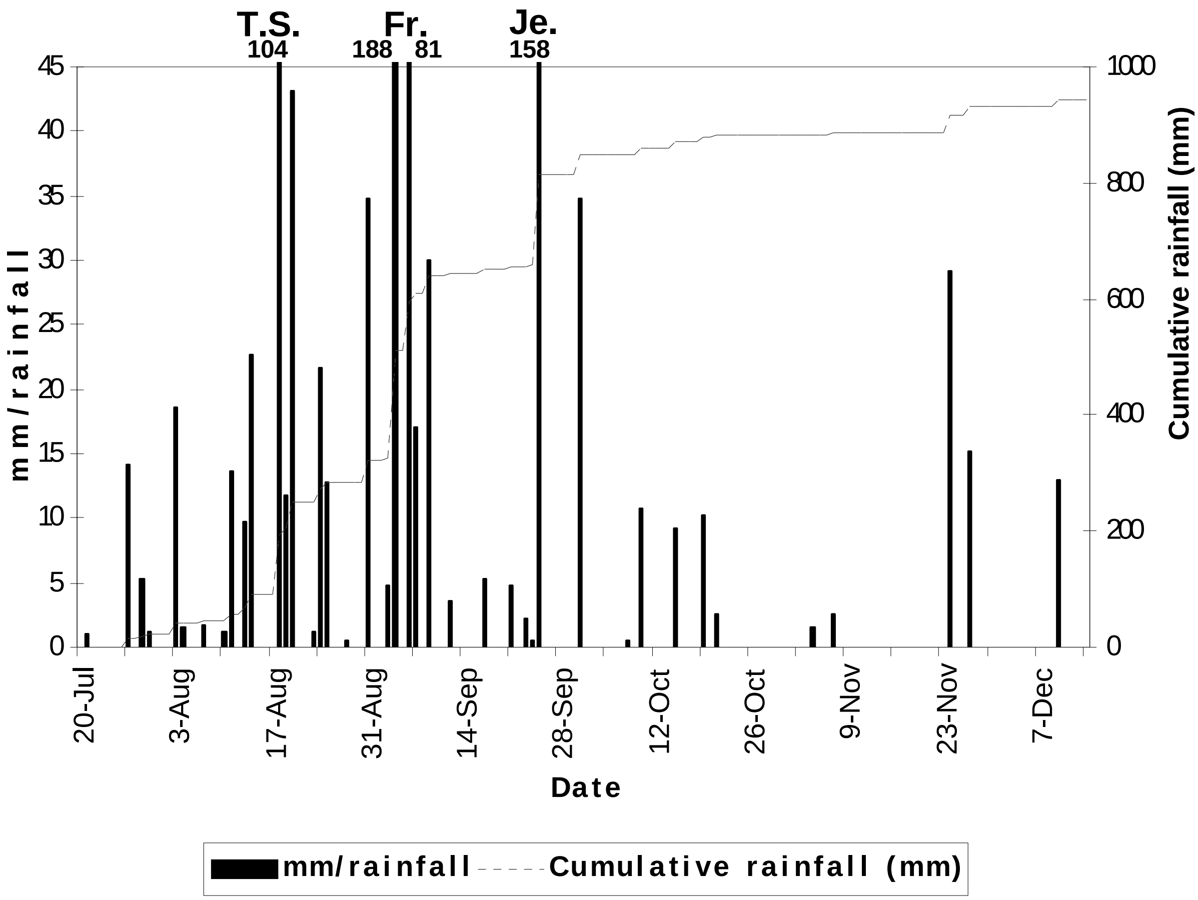


Figure 1. Brand means comparison of irrigation depth applied.
Different letters above the bars depict statistically different means at P <0.05

Table 4. Total irrigation depth applied to the time-based with rain sensor treatment (2-WRS) compared to individual soil moisture sensor-based treatments.

Treatment	TOTAL (mm)+
2-WRS	481 **a**
7-C	471 **a**
2-C	470 **a**
1-C	318 **b**
7-D	261 **c**
1-D	209 **d**
2-A	196 **d**
1-B	128 **e**
1-A	95 **f**
2-D	94 **f**
2-B	87 **fg**
7-B	85 **fg**
7-A	57 **g**

+Different letters within column depict statistically different means at P <0.05
See Table 1 for treatments abbreviations.



T.S.= Tropical Storm; Fr.= Hurricane Frances; Je.= Hurricane Jeanne

Figure 2. Rainfall events and Cumulative rainfall.