Set Points for Watermelon Drip Irrigation Using Capacitance Probes

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ABSTRACT: The utility of capacitance probes to continuously and accurately monitor soil water in drip irrigated melon production is explored in this study. The study also addresses the need for appropriate irrigation set points to trigger irrigation for stress-free growth and thus increased yield and profit. In 2008 and 2009, field experiments were conducted in a sandy Coastal Plain soil in South Carolina, USA to test two irrigation set points in melons using EasyAg capacitance probes. The probes were integrated within a commercially-available automated drip irrigation system. Three plant types were tested on raised beds with plastic mulch and under drip irrigation. The irrigation treatments had set points either at 15 or at 50% of available soil water capacity. The soil probes were installed between drip emitters (30 cm apart) and continuously recorded volumetric water contents at 10, 20, 30, 40, and 50 cm depths. Irrigation was automatically triggered on when the average water content in the root zone (top 30 cm soil) approached the irrigation set point. To minimize leaching, each irrigation event lasted for 30 min, and was only repeated if needed after an hour of irrigation rest. Each of the thirty-six plots was harvested four times and yield and fruit quality parameters were evaluated. On-site probe calibration showed factory calibration to be adequate for field purposes, suggesting the robustness of the probes for the sandy Coastal Plain soil. The 15% depletion set point showed significantly higher yield and plant biomass when compared to the 50% set point, and thus recommended herein. The capacitance probes facilitated triggering irrigation at pre-determined set points and simplified automation. Their use can improve irrigation efficiency, reduce leaching, and simplify management.

Keywords: Drip irrigation, Capacitance, Irrigation set points, Soil water content

INTRODUCTION

Most important in modern vegetable production systems is the use of drip irrigation and fertigation, i.e., the addition of nutrients through the drip system. Although drip irrigation has been an important benefit to the fruit and vegetable industry from the arid California to the humid Carolinas in the USA, many challenges confront the efficient management of this technology. Vegetable growers must make decisions on how frequently to irrigate and how long to run their system each time. Most vegetable growers lack adequate sensing technology and on-the-fly data interpretation capabilities to do an effective irrigation scheduling. Typical irrigation cycles are usually longer than necessary and thus wasteful of water, energy used for pumping, and money paid for leached nutrients. Depending on the soil type, stage of crop development, and climatic conditions, a well managed drip irrigated vegetable field most likely requires multiple daily applications to avoid water stress and yield reduction. The dominating sandy soils in the Southeast USA with low water holding capacities are especially vulnerable to water stress and water and nutrient leaching below the root zone. The capability to achieve intra-day irrigation triggering is most feasible with real-time knowledge of soil water via advanced sensors and remote data access capability. Efficient irrigation management also requires knowledge of the spatial and temporal root distribution and the threshold soil water depletion for stress-free growth. This information is currently lacking for many vegetables.

Among the vegetable crops, melons are most dominant in South Carolina, currently ranking as the sixth agriculturally-based revenue generator. A survey of the South Carolina Watermelon Association (SCWA) membership indicates that nearly all of its members use drip irrigation and polyethylene mulch for their commercial production. In comparison to sprinkler irrigation, drip irrigation under plastic mulch is complex. Drip irrigation is applied from a line of point sources to only part of the field, while the plastic mulch not only suppresses evaporation but also sheds rainfall to the edge of the mulched row from where it infiltrates and/or runs off (McCain et al., 2007). Without monitoring of soil water, it will be very difficult, if not impossible, to estimate the contribution of rainfall to the root zone under the plastic mulch.

Several studies have investigated root distribution of direct seeded and transplanted watermelon (e.g., Elmstrom, 1973; NeSmith, 1999), mostly showing the transplants having a more extensive lateral root system. Although the evidence is not conclusive, the watermelon root zone is most likely limited to the top 0.30 m of soil. Maintaining optimal soil water content in the limited root zone of vegetable crops can be difficult without continuous monitoring of the soil water status (Alva and Fares, 1998). Continuous monitoring of soil water not only facilitates optimal irrigation scheduling but also helps reduce leaching of water and nutrients below the root zone.

The combination of advances in electronics and success of the TDR technology have led to the availability of much new and relatively inexpensive soil water sensors with continuous monitoring capabilities. Several of these are based on soil dielectric properties and can be described as “TDR like” (Seyfried, 2004). Recent advances in microelectronics have improved the methods of measuring the dielectric constant of the soil-water-air medium as a means of determining soil water content (Fares and Alva, 2000). Among the success stories are the multi-sensor capacitance probes that have been used as an irrigation management tool in many places, such as in Australia since 1991 (Buss, 1993). Research results are a bit mixed as capacitance probes have been shown to be accurate and useful for real-time monitoring (Paltineanu and Starr, 1997), yet some studies argue that such sensors are less consistent (than TDR and neutron gauges) and show sensitivity to the electrical conductivity and temperature of irrigated soils, even when using soil-specific calibrations (Evett, 2007). On the other hand, current TDR and neutron probe sensors are too costly and difficult to use and thus not practical for on-farm irrigation scheduling. Obviously, further research and testing is required with the newer electronic sensors (Farahani et al., 2007) to determine their robustness, need for on-site calibration, and utility in different crops and soils.

Continuous monitoring of soil water dynamics lends itself to high-level, tactical irrigation scheduling in which the soil water depletion is frequently refilled to minimize the magnitude as well the duration of crop water stress. At present, vegetable growers use a wide range of soil allowable depletion levels or set points for irrigation timing, ranging from about 10% (i.e., wet root zone) to 50% (damp) of available soil water. Knowledge of threshold depletion levels for stress-free growth at different growth stages is fundamental to an effective soil-based and tactical irrigation scheduling for maximum yield and research is needed to quantify these depletion level for melons grown in the sandy Coastal Plain soils that occupy many parts of the southeastern USA.

The objectives of this research were: (1) To evaluate the utility of EasyAg TriSCAN 50 SDI-12 (Sentek Sensor Technologies, Stepney SA, Australia) soil water capacitance probe as a tool to determine soil water content for the purpose of drip irrigating melons according to pre-determined set points; (2) To determine appropriate set points in melons for automating drip irrigation scheduling in sandy Coastal Plains soils; and (3) To compare factory versus site-specific calibration of the probe in the prevailing sandy soils.

MATERIALS AND METHODS

This study was conducted at the Clemson University, Edisto Research and Education Center (EREC) near the town of Blackville in 2008 and 2009. EREC is in the southwestern part of South Carolina in Barnwell County and is considered part of the southeastern Coastal Plains of the United States. The field is located at 33° 21’ N latitude and 81° 19’ W longitude and 93 m above mean sea level. The soil is classified as Barnwell loamy sand with an available water capacity (AWC) of 0.08 m/m soil to a depth of 0.30 m. Soil texture determinations show sand prevailing to a depth of 0.20 m, loamy sand and sand at 0.30 m, sandy loam at 0.40 m and sandy clay at 0.50 m.

The experimental design was a split plot with irrigation as the main plot factor and plant type as the split plot factor. The experimental area was divided into four sections or replicates, each further divided into three main plots. The main plots were subdivided into three split plots. The plant type treatments were randomly assigned to each split plot and replicated four times. The three plant types (Seminis Vegetable Seeds, Oxnard, CA) included in the research were: the triploid cultivar ‘Wrigley’ non-grafted; ‘Wrigley’ grafted on the rootstock FR Strong (*Lagenaria spp*); and ‘Wrigley’ grafted on Chilsung Shintoza *(Curcubita moschata x Cucurbita maxima*).

Experimental plots consisted of two raised bed rows that were spaced 2.44 m center-to-center and covered with black plastic mulch. The width of the raised bed covered by plastic mulch was approximately 0.76 m. The experimental plots were irrigated using Aqua-Traxx^R drip tape (Toro Ag Irrigation, El Cajon, CA) with an emitter spacing of 0.30 m. The drip tape flow rate at 10 psi was 0.30 gph/emitter and 0.50 gpm/30.5 m length. Each split plot contained five treatment plants spaced 0.91 m apart (2.23 m^2/plant) for yield analysis. Also contained in the split plots were designated treatment plants for four, eight and twelve weeks after planting (WAP) analysis. Data analysis of these plants at the designated time included: wet and dry biomass, root cores and immature fruit weight.

All plants used in the research were propagated and grafted in a greenhouse at the EREC. Watermelon plants were planted 23 April, 2008 and 15 April, 2009. Production practices followed recommendations outlined in the Southeastern Vegetable Crop Handbook (2008). Each of the thirty-six plots was harvested four times in 2008 and three times in 2009. Watermelons of each treatment were harvested when they were mature (brown tendril near stem, yellow color on underside of fruit and a general loss of rind gloss) with end season fruit quality (i.e., sugar content, firmness, hollow heart) tested. All data were subjected to analysis of variance and means were separated by least significant difference (LSD) procedures (SAS Institute Inc., Cary, NC).

Three irrigation treatments were established in this research: a rainfed treatment that was only minimally irrigated for fertigation purposes, and two treatments based on a 50% and a 15% depletion level of available water capacity (AWC) as lower set points. All plots received the same amount of nutrients via fertigation and pre-plant application. In the top 0.30 m of the Barnwell loamy sand, mean volumetric water content at field capacity (FC) and permanent wilting point (PWP) were 17.4 and 6.1%, respectively, with the AWC equal to 11.3%. The volumetric water contents at the triggering lower set points for 15 and 50% depletion levels were thus 15.6 and 11.7%. When a given set point was detected, a 30 minute irrigation cycle was initiated followed by an hour of wait period. If the volumetric water content had not exceeded the upper set points after the wait period, then another 30 minute irrigation cycle was initiated. The upper set points were selected at arbitrary levels just below the field capacity, i.e., at 16.5 and 12.5% water contents for the 15 and 50% depletion levels. Once the upper set points were reached, the ongoing 30-min irrigation cycle was allowed to finish but no subsequent irrigation was triggered until lower set points were reached.

Each whole plot contained an EasyAg TriSCAN 50 SDI-12 soil water capacitance probe which was integrated within an automated drip irrigation system (EarthTec Solutions LLC, Vineland, New Jersey, USA). The capacitance probes were located adjacent to the drip irrigation line and between the 30 cm drip tape emitters (Fig. 1). Volumetric water content was recorded at 15 min intervals at 10, 20, 30, 40 and 50 cm depths and downloaded wirelessly to the internet for numerical and graphical analysis. The irrigation controller used the top three probe readings (i.e., 10, 20 and 30 cm depths) in each of the four whole plots per irrigation treatment to calculate the mean water content in the root zone. Readings from the lower depths (40 and 50 cm) were used to detect leaching from the root zone. A Motorola IRRInet Computerized Irrigation Controller (Motorola Inc., Schaumburg, IL, USA) was used to automate irrigation. The IRRInet system enables remote programming and supports various communication infrastructures of which the Wi-Fi (WLAN) system was employed herein. This system coupled with Virtual Network Computing (VNC) allowed monitoring and editing of ongoing irrigation programs.

Two separate field calibration tests were performed on the capacitance probes by comparing against direct soil sampling. The first calibration was conducted in Barnwell loamy sand that included eight probes. These probes were installed 25 April and field calibration was performed on 31 July, 2009. To obtain a wide range of soil wetness, three sensors were placed in a dry soil, three in moist, and two in wet. The second calibration test was conducted in a nearby Wagram sand, where five probes were installed on 19 August and calibration was performed on 8 October, 2009. Three probes were maintained in dry soil, one in moist, and two in wet. Rainout shelters were maintained over the dry sensors and multiple watering events were applied to the location designated as wet soil. The moist soil area was neither covered nor irrigated. Raw counts from each probe were recorded six times during a 10 minute period during each calibration event.

Fig. 1. Capacitance probe located adjacent to the drip line that is below the plastic mulch (top), blooms tagged on 29 May, 2008 (bottom).

At each calibration event, direct soil sampling included collecting three soil cores (137 cm^3) centered at each of the 10, 20, 30, 40, and 50 cm depths from around each of the probes. For each core, wet weight was determined immediately in the field, followed by dry weight determination after oven drying at 105° C for 48 hours. Bulk density measurements were used to convert gravimetric to volumetric water content for each core. An additional set of cores, three at each depth, were taken during calibration procedures for soil texture analysis. Raw counts obtained from the probes sensors at each particular depth level were converted into Scaled Frequencies (SF) according to: $SF = (F_A - F_S) / (F_A - F_W)$, where F_A, F_S, and F_W are the capacitance sensor frequencies in air, soil and non-saline water, respectively. The SF values were then converted to volumetric water content using the factory calibration equation.

RESULTS AND DISCUSSION

Calibration of Capacitance Probes

The volumetric water content for samples collected during the July 31 calibration procedure in Barnwell loamy sand ranged from 11.0 to 33.4%. Mean bulk density for all depths was 1.6 Mg/m^3, ranging from 1.41 Mg/m^3 at the 10 cm depth to 1.72 Mg/m^3 at the 30 cm depth. A soil hard pan between the 25 and 30 cm depths explains the high bulk density at the 30 cm depth. The volumetric water content for samples collected during the October 8 calibration procedure in Wagram sand ranged from 4.8 to 23.8%. Mean bulk density for all depths was 1.66 Mg/m^3 and was uniform for all depths with a standard deviation of 0.03.

The immediate interest in the calibration tests was to determine the correlation between the actual soil water contents based on the direct sampling method and the simultaneous probe readings based on the original factory calibration equation. As shown in Fig. 2, the correspondence was good (as implied by near unity slopes) with bias of less than 1% in water content. The bias was small (< 1%); it was positive in Barnwell loamy sand and negative in Wagram sand. The combined data for both soils and for the top 30 cm soil samples is also presented in Fig. 2 (bottom left). As shown, there were variations around the 1:1 line, which could be caused by a host of factors including but not limited to inherent probe sensitivity, errors in bulk density and water content by direct sampling, and possible errors associated with the small volume of influence of the probe sensors and the inherent small scale variability of soil water content in most field soils. Because of the latter source of error, Hignett and Evett (2008) did not recommend the calibration procedure used herein, although alternate procedures are equally prone to errors.

From our results (Fig. 2), the source of scatter around the 1:1 line is not obvious. It was noted that small changes (i.e., errors) in bulk density could lead to large changes in computed volumetric from gravimetric water content. For field irrigation purposes, the results for the top 30 cm soil layers are sufficiently accurate using factory calibration. The soils change substantially below the 30 cm depth, with increasing clay content. When these bottom layers (40 and 50 cm depths) were added to the calibration test (Fig. 2, bottom right), the underestimation at low and overestimation at high water contents was obvious with significant scatter around the 1:1 line.

Seasonal Soil Water Content

Figure 3 shows the mean value of water content in the top 0.3 m soil (i.e., root zone) for each irrigation treatment in 2008 and 2009. The seasonal mean water content in the 0-0.3 m (root zone) in the 15% depletion treatment was 16.2% in 2008 and 19.5% in 2009, whereas the pre-determined field capacity for the root zone was 17.4%. An early season malfunction in the 50% depletion irrigation relay during the 2008 season resulted in a spike in soil water content. Substantial rain events in 2009 contributed greatly to the soil water content as shown in Fig. 3.

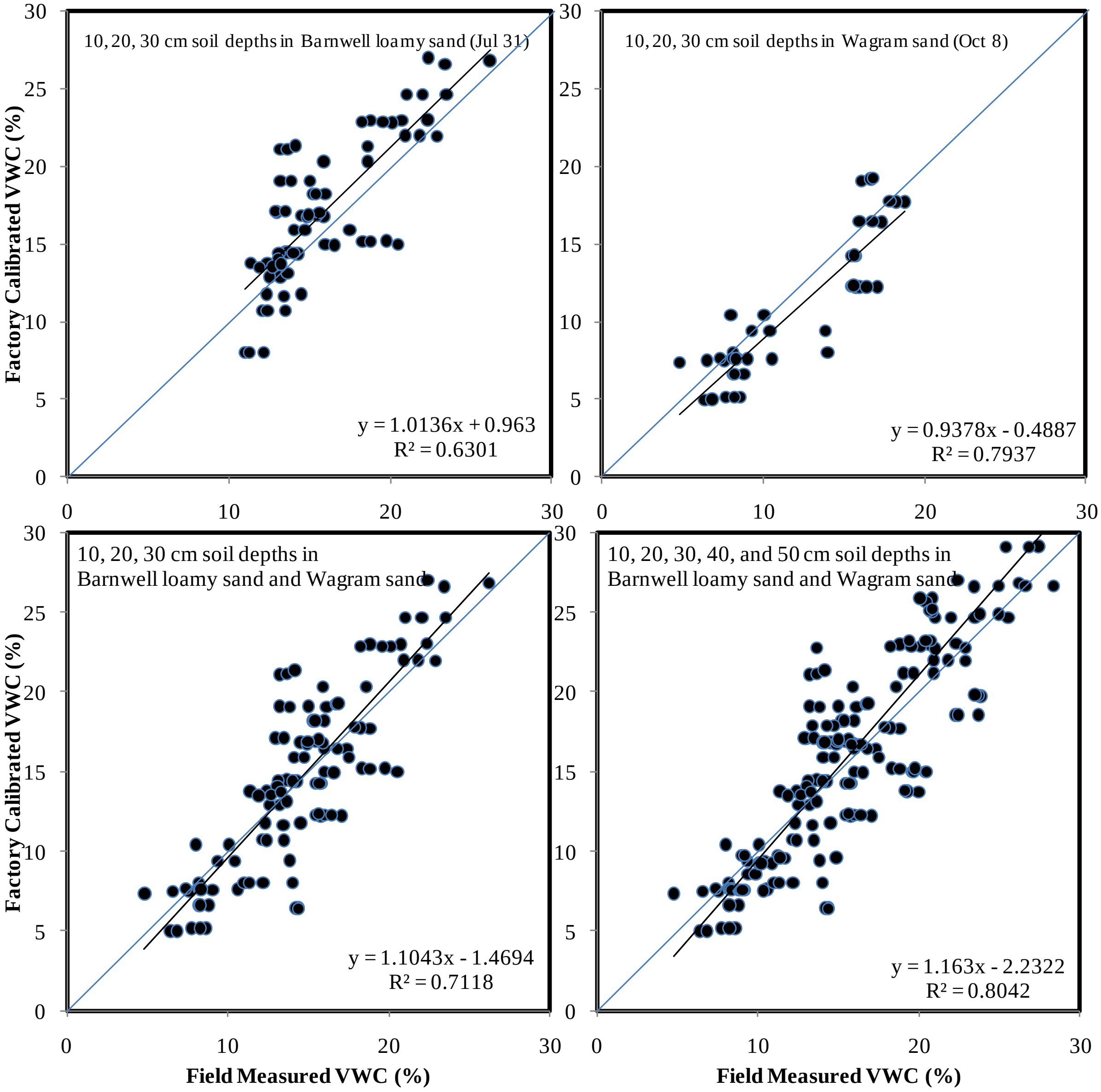

Fig. 2. Field measured versus probe readings of volumetric water contents (VWC) from the 10, 20 and 30 cm soil depths in Wagram sand and Barnwell loamy sand soils (top), and from 10, 20, and 30 cm (bottom left) and 10, 20, 30, 40, and 50 cm (bottom right) depths in both soils.

The fluctuations in soil water content were greatest at the 10 cm depth in both years, implying the zone with bulk of root water uptake activity. The greatest separation in soil water content for irrigation treatments in both years occurred during the fruit set growth stage. Although not shown, the seasonal mean value for water content in the 40 cm soil depth in 2008 was 22.9% with a standard deviation of 1.24. The seasonal mean value for water content in the 40 cm soil depth in 2009 was 21.6% with a standard deviation of 2.47. Leaching below the root zone is expected to be minimal as soil water fluctuations remained small at the 40 and especially at the 50 cm soil depths.

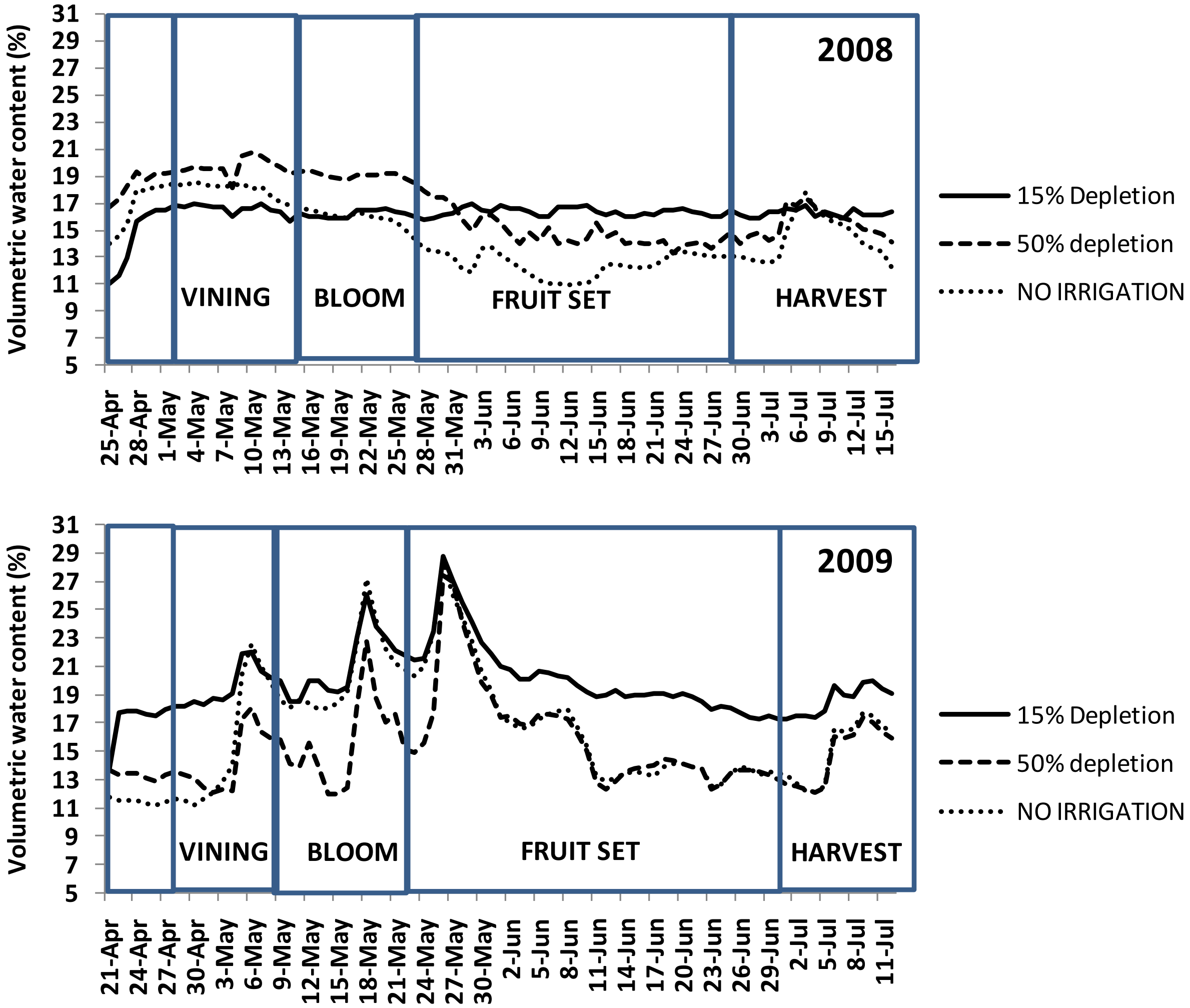

Fig. 3. Mean volumetric water contents in the top 0.3 soil for the three irrigation treatments in 2008 and 2009. Growth stages are also shown.

During the 85 day growing season of 2008, a total of 21.1 cm of rain fell. The 15% depletion treatment automatically triggered 88 times and delivered a total of 28.4 cm water. In contrast, the 50% depletion irrigation treatment automatically triggered 31 times (or less than half the 15% depletion treatment) delivering a total of 18.9 cm water. The rainfed (fertigation only) treatment was programmed to irrigate early in the season for plant establishment and then the rest of the season was automated for early morning fertigation only. These contributed a total of 11.9 cm water to the rainfed treatment.

The 2009 growing season was 90 days in length and precipitation was well above average at 49.8 cm, or more than twice the amount in 2008. The early spikes in water content as shown in Fig. 3 for 2009 are entirely due to rainfall events that inundated the plots and caused soil water to exceed field capacity. Also because of the excess rainfall, the 50% depletion irrigation treatment did not trigger during the 2009 growing season and received the same amount of irrigation via fertigation as the rainfed treatment, or a total of 9.4 cm water. The 15% depletion irrigation treatment automatically triggered 61 times in 2009 and delivered a total of 14.0 cm water. Because of the excess rainfall, irrigation in the 15% depletion in 2009 was half as much as in the 2008 season. The large contrast between 2008 and 2009 seasons highlights the need for soil water monitoring for effective scheduling. Without monitoring of soil water, any irrigation scheduling would have been more of an art than science considering that the contribution to soil water below mulch by rainfall is exceptionally difficult, if not impossible, to estimate.

Significance of Irrigation Set Points

Dry and wet biomass was determined at 30, 57, and 83 days after planting (DAP) for each irrigation treatment in 2008. There was no significant difference at 30 DAP but at both 57 DAP and 83 DAP, 15% depletion irrigation treatment showed a significantly greater dry biomass (P = 0.05). There was no significant difference in dry biomass between 50% depletion and no irrigation. In 2009, there were no significant differences in dry biomass at 48 DAP or 56 DAP. The 15% depletion irrigation treatment showed a significantly greater dry biomass at 90 DAP (P = 0.05). There was no significant difference in dry biomass between 50 % depletion and no irrigation. There was no significant differences between irrigation treatments for the fruit quality measurements; brix, hollow heart and black seed in either year. There were significant differences in 2008 for mean fruit weight and total fruit weight but not in 2009 (Table 1). It is noted that the significant yield differences between the 15 and 50% was only observed in 2008, simply because the excess rainfall removed irrigation treatment effects in 2009.

Table 1: Summary of yield data for the three irrigation treatments in 2008 and 2009.

Irrigation Treatment	Mean fruit weight (kg/melon)	LSD	P Value	t Grouping
2008 - 15% depletion	7.08	0.5717	<.0001	A
2008 - 50% depletion	7.01			A
2008 - no irrigation	5.71			B
2009 - 15% depletion	6.54	0.6547	0.738	A
2009 - 50% depletion	6.52			A
2009 - no irrigation	6.43			A
Irrigation Treatment	**Total fruit weight (kg/plot)**	**LSD**	**P Value**	**t Grouping**
2008 - 15% depletion	154.6	52.029	<.0001	A
2008 - 50% depletion	126.1			B
2008 - no irrigation	86.1			C
2009 - 15% depletion	112.3	50.991	0.3592	A
2009 - 50% depletion	100.5			A
2009 - no irrigation	96.5			A

Results from 2008 also confirm that proper irrigation set point for watermelon was the 15% depletion due to the significant yield increase; i.e., from 126 to 155 kg/plot in the 15% depletion treatment. The 2009 results are also interesting in that they clearly show that the entire investment in the irrigation system may not contribute much to profit as yield differences between rainfed, 50%, and 15% depletion levels were not significant due to excess rain.

CONCLUSIONS

Two different set points (15 and 50% depletion of available soil water capacity) were used to schedule drip irrigation for watermelons grown in Barnwell loamy sand. Capacitance probes provided real-time soil water dynamics by depth and facilitated the automatic triggering of irrigations when root zone mean water content reached the appropriate set points. Yield data showed a significant benefit to maintaining nearly a wet top soil in watermelon, i.e., at the 15% root zone depletion level.

The multi-sensor capacitance probes with factory calibration were found to be sufficiently accurate for irrigation scheduling purposes in typical Coastal Plains soils found in South Carolina. Although costly, use of capacitance probes for automating drip irrigation in high value vegetable crops could be economically feasible. Future work needs to substantiate set points for other vegetable crops, the performance of capacitance probes in other soil types, and the feasibility and economics of their use on the farm.

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