Greenhouse cucumber production using sensor-based irrigation

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Abstract. Cucumber is the most important vegetable produced in the U.S. Virgin Islands. Crop production is performed outdoors, with no information available regarding cultivation in a closed environment using precision irrigation to increase yield and save water. This study evaluated greenhouse production of different slicing cucumbers under increasing substrate volumetric water contents (VWC) to trigger irrigation automatically based on plant demand. Experiments were conducted in Fall 2016 and Spring 2017. We tested four cucumber varieties ('Boa', 'Corinto', 'Marketmore 76' and 'Verdon') and three substrate VWC to trigger irrigation (0.3, 0.4 and 0.5 m^3/m^3), on a split-plot design with three replications. Plants were transplanted into 9.45-L pots spaced 0.46 × 1.22 m, trained on a vertical plastic line, and fertigated with 5N-11P-26K hydroponic fertilizer (Peter's Professional; Everris, Geldermalsen, The Netherlands) and calcium nitrate. Irrigation was performed on-demand using one substrate moisture sensor per experimental unit formed by four pots. The irrigation system applied water automatically when the VWC dropped below the set thresholds. Sensor-based irrigation was effective to water the plants. The number of irrigation events and leaf anthocyanin content differed on both seasons. Total yield and total number of fruit/plant responded to increases in VWC and varieties ($P<0.05$). 'Corinto' cultivated with VWC 0.5 m^3/m^3 resulted in the highest yield at 57,445 kg/ha ($P=0.00269$). Marketable yield, fruit width and fruit hardness were variety-dependent. Fruit weight and length, leaf chlorophyll, plant growth index and fruit soluble solids content were influenced by the different seasons and varieties ($P<0.05$). 'Corinto' consistently showed higher yield in all VWCs used to trigger irrigation, producing longer and more fruit than the other varieties, being a promising cultivar for greenhouse cucumber production using sensor-based irrigation in the U.S. Virgin Islands.

Keywords. Cucumber (*Cucumis sativus*), Sensor-based irrigation, Water-saving technologies, Drip irrigation, Variety trial, Tropics

Introduction

Cucumber (*Cucumis sativus*) is one of the most important vegetables in greenhouse production in the U. S., particularly in California, Nevada and Florida. In 2014, cucumbers were cultivated in approximately 102 ha under protected environment, producing 32,940 t of fruit with a sales value of $77.6M (USDA, 2015). The crop is the leading vegetable grown in the U.S. Virgin Islands. According the latest census of agriculture, cucumber was ranked number one in area planted 18.6 ha and amount harvested 51 t (USDA, 2009). However, cucumber production in the U.S. Virgin Islands is mainly outdoors in soil. No information is available regarding the cultivation of cucumbers in protected environment using potting mix on hydroponics. Greenhouse cucumber production can be one alternative for local growers to generate income, expand agricultural production and increase food security in the territory.

One of the main challenges for growers interested in farm crop diversity is which variety to choose in new plantings. Vegetable performance trials are essential for vegetable growers to maximize revenue and reduce the risk of testing new crops (Ferrarezi et al., 2016). Cucumber varieties are classified in slicing and pickling types. Slicing cucumbers produce long, straight fruit with thick skin, with high commercial value and extended shelf life. There are also specialty selections known as burpless, heirloom and greenhouse cucumbers. All types have self-pollinating varieties for indoor cultivation.

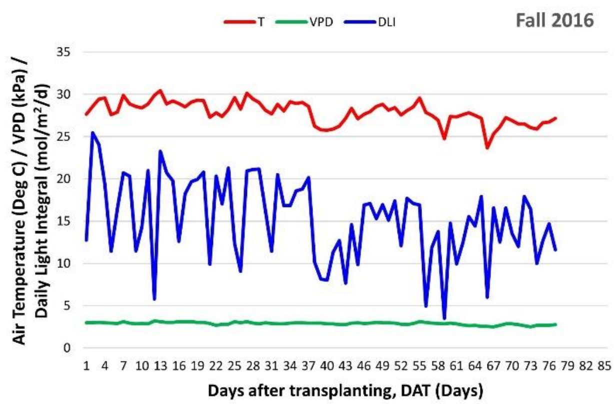
There are soil-, weather-, and plant-based methods to determine the volume, frequency, and rate of water for efficient irrigation. Growers generally make irrigation management decisions based on soil and plant visual observations, or use a rigid irrigation schedule set by timers (Nemali et al., 2007). Predefined daily cycles do not apply water and nutrients appropriately, causing water deficit or excess and reducing the yield potential due to the negative effect of stresses on plant physiology, with possibility of environmental contamination (e.g. nitrate percolation). Since water is scarce in the U.S. Virgin Islands, cropping systems that optimize water use are key to guarantee sustainable food production while achieving high yield. Soil-based monitoring systems are easy to implement, efficient and relatively inexpensive. Growers can use water potential (Shock and Wang, 2011) or volumetric water content (VWC) (Blonquist et al., 2005) to determine the amount of water available in the root zone. Automated irrigation based on soil tension has been used for decades (Shock and Wang, 2011), while using the VWC for system automation has become feasible in the recent years with the advent of capacitance sensors (Jones, 2007; Nemali and van Iersel, 2006). Volumetric water content measurements are useful to monitor soil moisture and control irrigation in real-time, allowing precise irrigation management. Sensor-based systems apply water automatically when the VWC drops below set thresholds, precisely irrigating based on plant demand.

This study evaluated greenhouse production of different slicing cucumbers under increasing substrate VWC to trigger irrigation automatically based on plant demand.

Material and Methods

Location. The studies were evaluated from Sept. 21 to Dec. 09, 2016 (Fall) and from Jan. 13 to April 7, 2017 (Spring) at the University of the Virgin Islands (UVI) Agricultural Experiment Station (AES), Kingshill, U.S. Virgin Islands (lat. 17°43’08” N, long. 64°47’46” W, 30 m above sea level).

Environmental conditions. Environmental data were recorded inside the greenhouse using a temperature and relative humidity sensor (HMP60; Vaisala, Vantaa, Finland) and quantum sensor (LI190R; Licor, Lincoln, NE). The vapor pressure deficit (VPD) was calculated from the saturated and actual air vapor pressure using the air temperature and relative humidity data (Fig. 1).



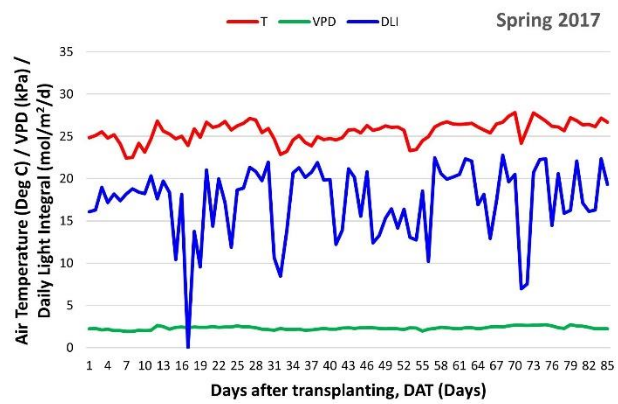


Fig. 1. Air temperature, vapor pressure deficit (VPD), and solar radiation over the two experiments performed in Fall 2016 (left) and Spring 2017 (right). Kingshill, U.S. Virgin Islands.

Plant material. Cucumber seeds were sown in 72-cell trays on Sept. 6, 2016 (Fall) and Jan. 3, 2017 (Spring), and transplanted into 9.45-L pots on Sept. 20, 2016 (Fall) and Jan. 12, 2017 (Spring). Pots were spaced at 0.46 × 1.22 m (representing 17,818 plants/ha). The potting mix used was Pro-Mix BX Mycorrhizae: perlite (70%: 30%). Potting mix nutrient concentrations were evaluated prior transplant in three samples. Average pH = 5.95, soluble salts = 0.43 dS/m, and nutrient concentrations (mg/L): nitrate-nitrogen = 0.35, ammoniacal-nitrogen = 5.52, phosphorus = 21.4, potassium = 65.5, calcium = 127.5, magnesium = 18, sulfur = 16.5, boron = 0.2, copper = 0.88, iron = 12.85, manganese = 6.43, zinc = 5.53, sodium = 59 and chloride = 55.53.

Treatments. We tested four cucumber varieties (‘Boa’, ‘Corinto’, ‘Marketmore 76’ and ‘Verdon’) and three substrate VWCs to trigger irrigation automatically (0.3, 0.4 and 0.5 m^3/m^3).

Automated irrigation. The automated irrigation controller was built using a data logger (CR1000; Campbell Scientific, Logan, UT), multiplexer (AM16/32B; Campbell Scientific), 16-channel AC/DC relay driver (SDM-CD16AC; Campbell Scientific), 36 10HS soil moisture sensors (Decagon Devices, Pullman, WA), and 36 24-VAC 1-inch (2.54 cm) solenoid valves (100DVF; RainBird, Azuza, CA) powered by a 12/24-VDC 500-VA transformer (31EJ02; Dayton, OH). The transformer power line was protected with a surge protector (3400-J 51110-SRG; Leviton, Melville, NY). The controller was powered using a 20-W solar panel (Infinium; ML Solar, Campbell, CA), connected to a 12/24-VDC 10-A Tracer solar charge controller (1210RN; EPSolar, Beijing, China) and two 12-VDC 7.2-Ah rechargeable batteries (Yuasa, Ebbw Vale, United Kingdom).

The irrigation system had 36 independent manifolds – one for each experimental unit. Manifolds were assembled using 1-inch (2.54 cm) PVC pipes. From each solenoid valve, a 2.44-m long × ¾-inch (1.9 cm) diameter polyethylene tubing was laid to receive 1-gallon-per-hour (GPH) (3.78-L) drip emitters. A dribble ring with four holes per plant was connected to the emitter to allow for even water distribution across the substrate surface. Water pressure was maintained at 25 psi using a pressure regulator. Due to the reduced number of drip emitters per irrigation line, additional 2-GPH (7.58-L) emitters were installed on each line to ensure proper closing of the valves after an irrigation event.

Irrigation was performed on-demand and controlled by one substrate moisture sensor per experimental unit. When the substrate VWC dropped below the set thresholds, the irrigation was turned on automatically for 90 seconds.

Cultural practices. Plants were trained on a vertical plastic line trellis, and fertigated with 5N-11P-26K hydroponic fertilizer and calcium nitrate (total of 150 mg N/L and 140 mg Ca/L).

Measurements. We measured VWC (over time), number of irrigation events (over time), total and marketable yield (determined weekly and totalized at the end), fruit number, fruit size (weight, length, and width), fruit soluble solids content using a refractometer (RF15; Extech Instruments, Nashua, NH), plant growth index [(height + width 1 + width 2) / 3] on days 50 (Fall) and 54 (Spring), and fruit hardness. Leaf anthocyanin and chlorophyll content indexes (non-destructive analysis) were measured in Fall (day 49) and Spring (day 75). Anthocyanin was measured with a portable anthocyanin content meter (ACM-200 plus; Opti-Sciences, Hudson, NH), and chlorophyll using a chlorophyll concentration meter (MC-100; Apogee Instruments, Logan, UT).

Experimental design and Statistical analysis. Treatments were arranged on a split-plot design, with three replications. Each experimental unit had four plants / variety for a total of 36 plants per variety and 144 per trial. Data were analyzed using a mixed model procedure in SAS (version 9.4; SAS Institute, Cary, NC). Errors were assumed to be normally and independently (NID) distributed. Probability values ≤ 0.05 were considered statistically significant.

Results and Discussion

Sensor-based irrigation was effective to water the plants automatically only when the VWC dropped below set thresholds (Fig. 2). Graphs indicate the irrigation was effectively turned on when substrate VWC reached the treatment thresholds (left = VWC of 0.3 m^3/m^3; center = VWC 0.4 m^3/m^3; and right = VWC 0.5 m^3/m^3; Fig. 2). Results are consistent with several studies using sensor-based automated irrigation (Ferrarezi et al., 2014; 2015; Nemali and van Iersel, 2006). Replication differences are expected, and explained by the use of independent experimental units, variations in moisture caused by container positioning in the greenhouse, sensor installation, and the natural variability between plants, which was also reported by Ferrarezi et al. (2017). Data collected during Fall 2016 (Fig. 2A) were more stable than Spring 2017 (Fig. 2B). The reason for such variation is unknown.

The number of irrigation events was 62.5% higher in Spring 2017 compared to Fall 2016 ($P<0.0001$, Table 1). There was no effect of increasing VWC values to trigger irrigation on this variable. Treatments with high VWC tend to have higher substrate moisture and number of irrigations (Ferrarezi et al., 2017).

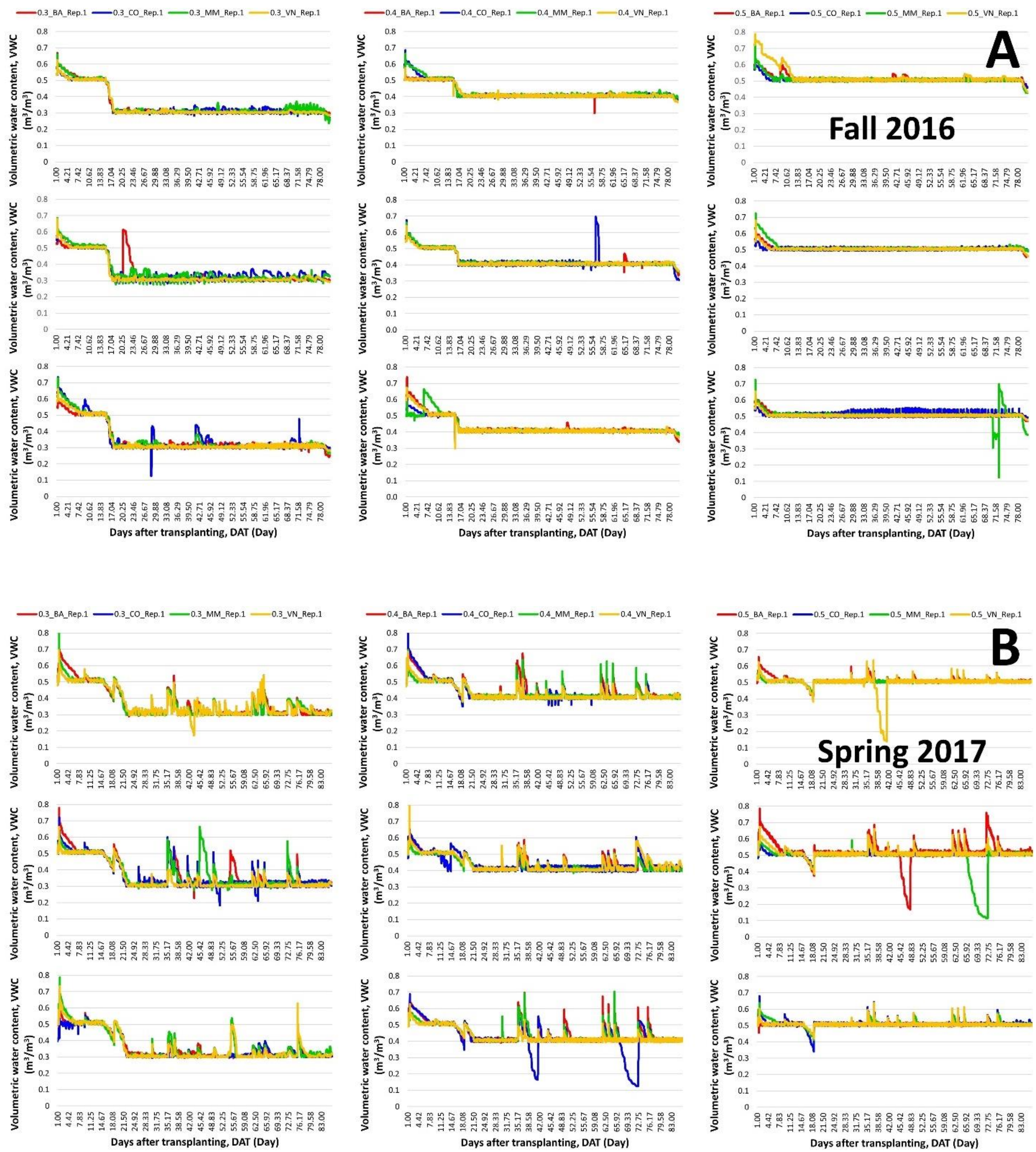


Fig. 2. Volumetric water content (VWC) in Fall 2016 (A) and Spring 2017 (B). VWC treatment thresholds: graphs in the left = VWC of 0.3 m^3/m^3 to trigger irrigation; center = VWC 0.4 m^3/m^3; and graphs in the right = VWC 0.5 m^3/m^3. Kingshill, U.S. Virgin Islands.

Table 1. Number of irrigation events, marketable yield, fruit width and hardness, and leaf anthocyanin of four cucumber varieties ('Boa', 'Corinto', 'Marketmore 76' and 'Verdon') cultivated in two seasons (Fall 2016 and Spring 2017) and under three volumetric water contents (VWC) to trigger irrigation (0.3, 0.4 and 0.5 m^3/m^3). * Significant at P<0.05. Kingshill, U.S. Virgin Islands.

	Irrigation count (nr.)	Marketable yield (kg/ha)	Fruit width (cm)	Fruit hardness (kgf)	Leaf anthocyanin (ACI)
Season					
Fall 2016	456 ± 67 b	25,796 ± 7,837	4.92 ± 0.26	8.04 ± 0.54	6.70 ± 0.80 a
Spring 2017	741 ± 211 a	23,552 ± 10,224	4.84 ± 0.18	7.74 ± 0.53	5.14 ± 0.37 b
VWC					
0.3 m^3/m^3	641 ± 252	23,176 ± 6,024	4.91 ± 0.25	8.04 ± 0.47	5.84 ± 0.71
0.4 m^3/m^3	535 ± 120	21,723 ± 5,991	4.86 ± 0.20	7.72 ± 0.65	6.08 ± 0.84
0.5 m^3/m^3	619 ± 125	29,122 ± 11,621	4.88 ± 0.23	7.91 ± 0.49	5.83 ± 0.77
Variety					
'Boa'	513 ± 71	27,237 ± 7,437 b	5.14 ± 0.07 a	8.44 ± 0.44 a	6.27 ± 0.67
'Corinto'	631 ± 151	38,243 ± 9,044 a	4.96 ± 0.09 a	8.22 ± 0.46 ab	5.64 ± 0.61
'Marketmore 76'	661 ± 270	14,356 ± 4,210 c	4.98 ± 0.14 a	7.60 ± 0.60 bc	6.04 ± 0.75
'Verdon'	589 ± 157	18,858 ± 4,814 bc	4.45 ± 0.28 b	7.31 ± 0.42 c	5.71 ± 0.98
			p-value		
Season	<0.0001*	0.3899	0.2856	0.1153	<0.0001*
VWC	0.4018	0.0560	0.8218	0.3679	0.6612
Season*VWC	0.5455	0.5887	0.5547	0.4470	0.8657
Variety	0.4371	<0.0001*	<0.0001*	0.0002*	0.2523
Season*Variety	0.6013	0.4143	0.4034	0.4810	0.2804
VWC*Variety	0.5731	0.05040	0.6434	0.1594	0.4542
Season*VWC*Variety	0.7486	0.8300	0.9213	0.1778	0.1733

Total yield and total number of fruit per plant responded to increase in VWC and were different among varieties (P<0.05, Fig. 3). 'Corinto' cultivated with VWC 0.5 m^3/m^3 resulted in the highest yield at 57,445 kg/ha (P=0.00269, Fig. 3). The number of fruit per plant followed a similar trend (P=0.0293, Fig. 3). 'Corinto' is a parthenocarpic slicing cucumber hybrid with high yield potential and strong vigor, with intermediate resistance to powdery mildew and viruses (Torres and Mazereeuw, 2013), which may explain the outstanding performance. The marketable yield of 'Corinto' was higher than all other varieties, totaling 38,243 kg/ha (P<0.0001, Table 1).

Fruit width was 11% smaller on 'Verdon' (P<0.0001, Table 1). This variety also exhibited the lowest fruit hardness, what can reduce shelf life (P=0.0002, Table 1). Leaf anthocyanin content was 30% higher in Fall 2016 (P<0.0001, Table 1).

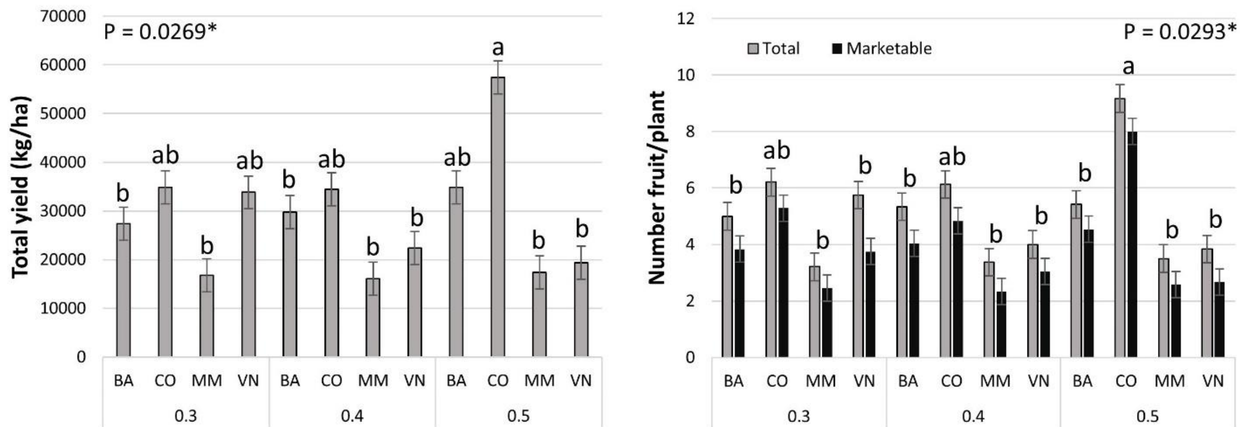


Fig. 3. Total yield (left) and number of fruit per plant (right) in four slicing cucumber varieties (‘Boa’ [BA], ‘Corinto’ [CO], ‘Marketmore 76’ [MN] and ‘Verdon’ [VN]) subjected to increasing volumetric water contents to trigger irrigation automatically (0.3, 0.4 and 0.5 m^3/m^3). Kingshill, U.S. Virgin Islands.

Fruit weight was low on ‘Verdon’ in Fall 2016 and on ‘Marketmore 76’ in Spring 2017 (P=0.001, Fig. 4). Fruit were 35% longer on ‘Verdon’ in Fall 2016 and 75% longer in Spring 2017 compared to the other varieties (P=0.0074, Fig. 4). As ‘Verdon’ presented the lowest fruit hardness, total yield and fruit weight (Table 1 and Fig. 3), this variety is not suitable for greenhouse production in the U.S. Virgin Islands. Fruit soluble solids content was higher on ‘Marketmore 76’ and ‘Verdon’ on both seasons (P=0.0004, Fig. 4). Leaf chlorophyll content decreased in Spring 2017 (P=0.0031, Fig. 4). ‘Boa’, ‘Corinto’ and ‘Marketmore 76’ presented the highest plant growth index in Fall 2016, with all varieties having drastically reduced plant growth in Spring 2017 (P=0.0018, Fig. 4). Reasons for such drop were not identified.

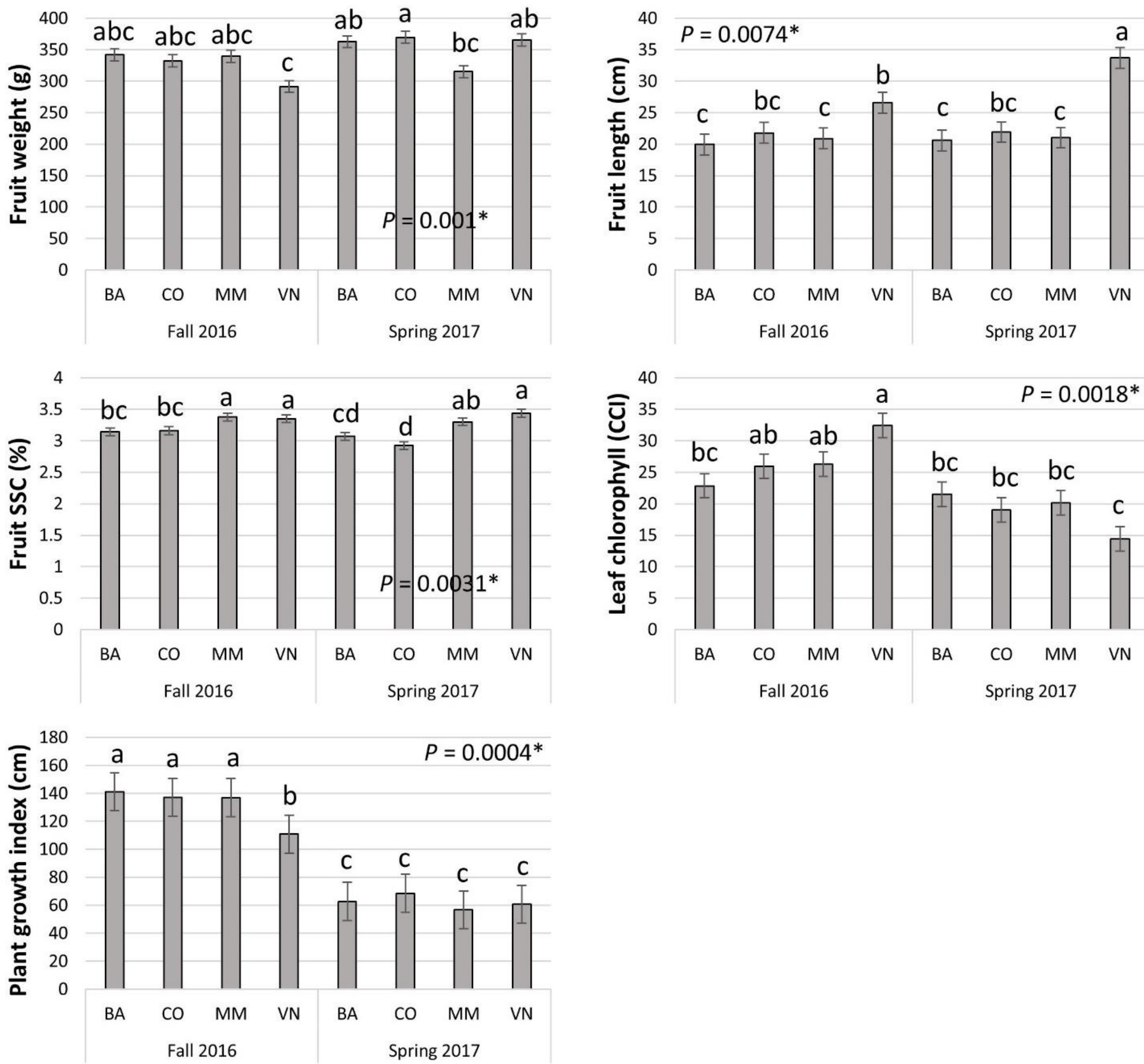


Fig. 4. Fruit weight, fruit length, fruit soluble solids content (SSC), leaf chlorophyll content and plant growth index in four slicing cucumber varieties ('Boa' [BA], 'Corinto' [CO], 'Marketmore 76' [MN] and 'Verdon' [VN]) cultivated in two sequential seasons (Fall 2016 and Spring 2017). Kingshill, U.S. Virgin Islands.

Conclusions

'Corinto' consistently showed higher yield in all VWCs used to trigger irrigation automatically, producing longer and more fruit than the other varieties, being a promising material for greenhouse cucumber production using sensor-based irrigation in the U.S. Virgin Islands.

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References

Ferrarezi, R.S. and Testezlaf, R. 2017. Automated ebb-and-flow subirrigation for citrus liners production. I. Plant growth. Agricultural Water Management 192: 45-57.

Ferrarezi, R.S.; Weiss, S.A.; Geiger, T.C.; Beamer, K.P. 2016. Edible-pod peas as high-value crops in the U.S. Virgin Islands. HortTechnology 26(5): 683-689.

Ferrarezi, R.S.; van Iersel, M.W.; Testezlaf, R. 2014. Subirrigation automated by capacitance sensors for salvia production. Horticultura Brasileira 32(3): 314-302.

Ferrarezi, R.S.; van Iersel, M.W.; Testezlaf, R. 2015a. Monitoring and controlling ebb-and-flow subirrigation with soil moisture sensors. HortScience 50(3): 447-453.

Jones, H.G. 2007. Monitoring plant and soil water status: Established and novel methods revisited and their relevance to studies of drought tolerance. Journal of Experimental Botany 55: 2427-2436.

Nemali, K.S. and van Iersel, M.W. 2006. An automated system for controlling drought stress and irrigation in potted plants. Scientia Horticulturae 110: 292-297.

Nemali, K.S.; Montesano, F.; Dove, S.; van Iersel, M.W. 2007. Calibration and performance of moisture sensors in soilless substrates: ECHO and Theta probes. Scientia Horticulturae 112: 227-234.

Shock, C.C. and Wang, F.-X. 2011. Soil water tension, a powerful measurement for productivity and stewardship. HortScience 46: 178-185.

Torres, L.M. and Mazereeuw, J.P. 2013. Cucumber hybrid ‘Corinto’. US Patent US 8,399,740 B2, filed May 8, 2009, and issued Mar 19, 2013.

U.S. Department of Agriculture. 2015. Census of Agriculture: Census of Horticultural Specialties (2014). 14 Oct. 2017. https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Census_of_Horticulture_Specialtes/HORTIC.pdf.

U.S. Department of Agriculture. 2009. Census of Agriculture: Virgin Islands of the United States Territory and Island Data (2007). 14 Oct. 2017. https://www.agcensus.usda.gov/Publications/2007/Full_Report/Outlying_Areas/usvi.pdf.