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EFFECT OF SENSOR-BASED HIGH FREQUENCY IRRIGATION ON BELL PEPPER YIELD AND WATER USE

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ABSTRACT

Three levels of sensor based high frequency irrigation treatments and four levels of twice daily irrigation treatments were applied to bell pepper (*Capsicum annuum* L.) in 2002 to test the effect on yield and seasonal irrigation volume, water use efficiency, and soil moisture content in the root zone. Sensor based treatments used a soil moisture sensor buried 10 cm deep within the crop root zone to maintain soil moisture at a set level. The two sensor based irrigation treatments with the largest seasonal irrigation volume resulted in yields similar to the two largest seasonal volume daily irrigation treatments (marketable yields ranged between 17,000 and 20,000 kg/ha for these treatments), but used approximately 50% less seasonal irrigation water. This resulted in irrigation water use efficiencies of 1209-2316 kg/ha/m^3 for the sensor based treatments while those of daily treatments ranged from 703 to 1612 kg/ha/m^3. Sensor based irrigation treatments resulted in significantly higher soil volumetric moisture levels at the 15 and 30 cm depths. The results indicate that high frequency irrigation events based on soil moisture sensor control can maintain crop yields while reducing irrigation water requirements; however, future research is needed to reproduce this first year of results.

INTRODUCTION

Vegetable production in Florida covers approximately 142,000 ha with a value of \$1.2 billion annually. Of this production, bell pepper (*Capsicum annuum* L.) covers 9,000 ha and has a value of \$300 million. Statewide average bell pepper yields are typically 35,000 kg/ha (Witzig and Pugh, 2001).

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Florida has the second largest withdrawal of ground water for public supply in the United States (Solley et al., 1998) and ranks thirteenth nationally for agricultural self-supplied water use; yet, it is the top water user in this category in the humid region (Solley et al., 1998). Agricultural self-supply accounts for 35% of fresh ground water withdrawals and 60% of fresh surface water withdrawals. This category is the largest component of freshwater use with 45% of the total withdrawals in Florida (Marella, 1999).

The primary use of water in agriculture is irrigation to supplement rainfall during the dry crop production periods. Historically, the humid region receives more precipitation than it loses to evapotranspiration (ET) on average each year. However, short drought periods have been shown to significantly reduce yields and quality of several vegetables (Singh, 1989; Stansell and Smittle, 1980) including bell pepper (Simonne, 2000).

Detailed recommendations for commercial vegetable production are available in Florida (Maynard and Olson, 2001). While vegetable production aspects are covered in detail, irrigation recommendations are mostly intended for over-head and seepage irrigation systems (Simonne et al., 2001). Bell peppers are typically grown in raised beds covered with plastic film and drip irrigation. Although this method has the potential to be very efficient, over irrigation is a common occurrence due to inadequate irrigation scheduling and the low soil water holding capacity of sandy soils commonly found in Florida. Automation of irrigation systems based on soil moisture sensors may improve water use efficiency by maintaining soil moisture at optimum levels rather than a cycle of very wet to very dry during the day as a result of once per day manual irrigation events. This is even more critical in Florida where available soil moisture is typically 6-8% by volume or less.

Automation of irrigation systems and the use of soil moisture sensing devices such as tensiometers has been investigated by many researchers. Automation generally consists of a soil moisture or water level sensor, a control system, and irrigation system components. Switching tensiometers have been used in various applications such as fresh market tomatoes (Smajstrla and Locascio, 1994), citrus (Smajstrla and Koo, 1986), and Bermuda grass (Augustin and Snyder, 1984) to automatically control irrigation events based on preset soil matric potential limits. Smajstrla and Koo (1986) discussed the problems associated with using tensiometers to initiate irrigation events in Florida. Problems included entrapped air in the tensiometers, organic growth on the ceramic cups, and the need for re-calibration. Torre-Neto et al. (2000) described an automated irrigation system for citrus production based on tensiometers and wireless communication that is able to account for spatial production variables (e.g. different levels of maturity or varying soils types). Tensiometers have typically been used to initiate a preset timed irrigation event; therefore, the irrigation event was stopped after a

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preprogrammed irrigation time rather than actual soil moisture conditions (Smajstrla and Koo, 1986; Smajstrla and Locascio, 1994; Phene and Howell, 1984; Torre-Neto et al., 2000). Phene and Howell (1984) used a custom made soil matric potential sensor to control subsurface drip irrigated processing tomatoes. Their results indicated that yields of the automated system were similar to those from tomatoes irrigated based on pan evaporation with the potential to use less irrigation water.

Although used extensively to automate irrigation systems, tensiometers tend to require more maintenance compared to solid state sensors such as Granular Matrix Sensors (GMS) or Time Domain Reflectometry (TDR) sensors. Granular Matrix Sensors are similar to tensiometers in that they are made of a porous material that reaches equilibrium with the soil moisture tension, which is correlated with an electrical signal based on a calibration equation. These sensors have been used in a wide range of applications to initiate automatic irrigation from onion and potato (Shock et al., 2002) to urban landscapes (Qualls et al., 2001). Generally, these sensors have been found to require less maintenance than traditional tensiometers. Similar to many of the automatic tensiometer controlled irrigation systems, Shock et al. (2002) described a system that used GMS to initiate a timed irrigation event. Nogueira et al. (2002) described an automatic subsurface drip irrigation control system used in a sweet corn/peanut crop rotation. This system used TDR sensors to maintain soil moisture with two preset limits (upper and lower soil moisture thresholds). Although GMS and TDR sensors both provide a mechanism to control irrigation systems, GMS sensors may not provide adequate control for irrigation in sandy Florida soils with factory calibration equations for generic soil types (Irmak and Haman, 2001).

We hypothesize that an automatic system with feedback based on soil moisture conditions for complete control of the irrigation system (i.e. “on” and “off”) has the potential to provide maximum water use efficiency compared to manual irrigation events or semi-automatic irrigation events that are initiated by a sensor and stopped based on a preprogrammed irrigation time. The objectives of this experiment were to investigate the effect of automatic sensor initiated high frequency irrigation treatments against manually initiated daily irrigation treatments on 1) bell pepper marketable yield, 2) water use 3) soil moisture content, and 4) to provide calibration data for the sensor and valve combination.

MATERIALS AND METHODS

This experiment was conducted at the North Florida Research and Education Center, Suwannee Valley near Live Oak, FL on a Lakeland fine sand (thermic, coated, Typic Quartzipsamment, Calhoun et al., 1974). Six week old ‘Brigadier’ bell peppers were transplanted on March 29, 2002. The soil was fumigated with a 66:33 (w:w) methyl bromide:chloripicrin mix at a rate of 448 kg/ha. Immediately after fumigation, plastic mulch and drip irrigation tubing (Roberts Irrigation

Products Inc., San Marcos, CA; 279 l/100 m/hr flow rate at 69 kPa; 30 cm emitter spacing; 0.2 mm thickness) was laid. Following current recommendations (Maynard et al., 2001) and soil test results, fertilization consisted of 224-22-224 (224-10-186 N-P-K) kg/ha, applied as a preplant application of 560 kg/ha of 13-4-13 (13-2-11 N-P-K), and weekly injections of combinations of potassium nitrate (KNO_3) and ammonium nitrate (NH_4NO_3) that supplied 12, 16, 20, 16, and 12 kg/ha of N, and 8, 8, 20, 8 and 8 kg/ha of K_2O, for growth stages 1 to 5, respectively (Maynard et al., 2001). Pesticide application followed state recommendations (Maynard et al., 2001). Four replications were organized in a randomized complete block design where plots were 6 m long, 1 m wide, and spaced 1.5 m apart. This resulted in approximately 1075 linear meters of bed per hectare and 7051 plants/ha.

Two types of irrigation scheduling were implemented. The first type consisted of four levels of manual irrigation (M1 = 0.33*M3, M2 = 0.67*M3, M3, M4 = 1.33*M3) scheduled daily based on Class A pan evaporation (Ep) from the previous day. Irrigation volumes were calculated based on the crop stage of growth and with pan adjustment factors (Simonne et al., 2001). The M3 target irrigation volume was determined using the conversion of 2.54 mm of Ep corresponding to 248 l/100 m of irrigated bed. The M1, M2, M3, and M4 irrigation rates were adjusted proportionally with the number of drip tape lines installed in the planting bed. For example, M3 included three drip lines for irrigation; whereas, M1 included one line. Multiple drip lines in each bed were placed in the center of the bed. Irrigation events were initiated manually twice each day, one event in the early morning and one at mid afternoon. The second type of irrigation scheduling was accomplished by battery operated solenoid valves, one for each treatment A1, A2, and A3, connected to soil moisture sensors (Model Flori 1 includes valve and sensor, Netafim USA, Fresno, CA). Each valve was operated by an integral controller and provided a relative watering target (0 for 'dry' to 10 for 'wet'). The valve manufacturer does not provide a calibration between the control setting and soil moisture content. Treatments A1, A2, and A3 were set at '3', '6', and '8', respectively. The soil moisture sensor attached to the valve operates based on the dielectric properties of the soil and was buried 10 cm deep in a horizontal position in one plot of each automatic irrigation treatment (A1, A2, and A3).

Once the pepper plants were established, time domain reflectometry (Model CS615, Campbell Scientific, Inc., Logan, UT) probes were installed between 23 and 26 days after transplanting (DAT) beneath three replicates in each experiment. Probes were installed perpendicular to the length of the beds at 15 and 30 cm depths in each plot. They were installed approximately 50 cm apart parallel to the length of the beds to eliminate any potential interference among probes. The TDR probes have 30 cm long wave guides and were connected to a data logger (Model CR-10, Campbell Scientific, Logan, Inc., UT) with a relay multiplexer (Model AM416, Campbell Scientific, Inc., Logan, UT). Soil moisture data were collected hourly, stored and downloaded for post processing every one to two weeks. Hourly soil moisture values were averaged for each day and analyzed with ANOVA procedures with SAS (SAS, 2001).

Totalizing flow meters were installed on all the treatments to measure total flow distributed to all replicates in each treatment. Flow meter readings were recorded daily. Water use efficiency (WUE, kg/ha/m^3) was calculated as marketable yield (MY, kg/ha) divided by seasonal irrigation water use (WU, m^3).

Harvest occurred on June 11, 2002, which was 74 DAT. Peppers were harvested and graded into Fancy, US Number 1, US Number 2, and culls according to USDA standards (USDA, 1989). Yield data were analyzed with analysis of variance procedure using PROC GLM. Treatment differences were analyzed with Duncan's Multiple Range Test. Note that different letters in tables indicate statistical differences ($p<0.05$) based on Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

A total of 95 mm of rainfall occurred during the growing season, with 54 mm occurring in three storm events within the last two weeks of the season. Rainfall contributed minimally to the crop water requirements due to the plastic mulch covering the beds.

The daily and the automatic irrigation treatments provided a gradient of water applied throughout the crop season (table 1). Treatment M2 resulted in 67.0 m^3 per 100 m of linear bed (67.0 m^3/100 m), while 25.2, 44.0, and 58.1 m^3/100 m was applied to A1, A2, and A3, respectively. The greatest amount of irrigation water was applied to M4 at 115.1 m^3/100 m. As a result, water use efficiency was highest on the A1 treatment, 2316 kg/ha/m^3, and lowest on the M4 treatment at 703 kg/ha/m^3 (fig. 1). Water use efficiency was similar between A2, M1, and M2 at 1709, 1403, and 1612 kg/ha/m^3, respectively. The treatments with the highest irrigation water application volume resulted in the lowest water use efficiency of 1209, 900, and 703 kg/ha/m^3 for A3, M3, and M4, respectively. Thus, increasing irrigation volume did not necessarily result in higher yields.

Treatment M2 resulted in the highest marketable yield of 26,394 kg/ha ($p<0.05$). Marketable yields of M3, M4, A2, and A3 ranged between 17,000 and 20,000 kg/ha (table 2). Lowest marketable yield was measured on treatments A1 and M1. The statistical trend in total yield (marketable yield plus culls) was similar to the trend in marketable yield indicating that culls were not a significant factor. Treatment M2 resulted in the highest Fancy yield at 16,229 kg/ha, while the other treatments were not statistically different between 6,536 and 9,743 kg/ha. US number 1 yield was similar across two categories with M1, M2, M3, M4, and A3 in the highest yield category, while M1, M2, M4, A1, A2, and A3 were in the lowest category. Yield was not statistically different across all treatments in the

US number 2 category. The results indicate that while yield was maximized in the M2 treatment, the lower yields in the A2 and A3 treatments were similar to the M3 and M4 treatments with approximately 50% less water used to achieve those yields. This resulted in the higher water use efficiency values in the A2 and A3 treatments compared to the M3 and M4 treatments.

Table 1. Seasonal irrigation volume, water use efficiency, and daily average soil moisture content in the crop root zone for bell pepper in 2002.

Treatment	Seasonal Irrigation Volume (m^3/100m)	Water Use Efficiency (kg/ha/m^3)	Average Daily Soil Moisture Content at 30 cm (cm^3/cm^3)	at 15 cm (cm^3/cm^3)
M1	42.2	1403	0.11 d	0.10 ef
M2	67.0	1612	0.13 b	0.11 e
M3	91.1	900	0.13 b	0.12 d
M4	115.1	703	0.14 b	0.13 c
A1	25.2	2316	0.12 c	0.10 f
A2	44.0	1709	0.14 b	0.18 a
A3	58.1	1209	0.16 a	0.16 b

Table 2. Marketable, total, and graded yield data for bell pepper in 2002.

Treatment	Marketable Yield (kg/ha)	Total Yield (kg/ha)	Fancy Yield (kg/ha)	US number 1 Yield (kg/ha)	US number 2 Yield (kg/ha)
M1	14 472 c	16 932 c	6 536 b	6 116 ab	1 821 a
M2	26 394 a	28 353 a	16 229 a	6 749 ab	3 416 a
M3	20 014 b	22 112 b	8 772 b	9 133 a	2 109 a
M4	19 769 b	21 332 b	8 874 b	7 613 ab	3 281 a
A1	14 240 c	16 796 c	7 327 b	4 649 b	2 263 a
A2	18 382 bc	22 384 b	9 743 b	5 631 b	3 008 a
A3	17 150 bc	21 066 b	7 553 b	6 461 ab	3 136 a

Average daily soil volumetric moisture content is presented for each treatment at the 15 and 30 cm depths in table 1. Treatment A2 resulted in the highest average daily soil moisture content of 0.18 cm^3/cm^3 at the 15 cm depth ($p<0.05$) and A3 resulted in the next highest soil moisture content of 0.16 cm^3/cm^3. A1 and M1 resulted in the lowest soil volumetric moisture content. Although M2 resulted in the highest yield, this irrigation regime also led to the next to lowest average daily soil moisture content at the 15 cm depth. At the 30 cm depth, the A3 treatment resulted in the highest average daily soil moisture content of 0.16 cm^3/cm^3, but the differences were not as apparent as at the 15 cm depth (table 1). The soil moisture content at the 30 cm depth across treatments M2, M3, M4, and A2 was not statistically different ($p<0.05$). Treatments M1 and A1 resulted in the lowest soil moisture content at the 30 cm depth.

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The constant soil moisture status provided by high frequency sensor based irrigation events resulted in a more stable soil moisture level when compared to daily manual irrigation events. This is because the soil on the experimental site is a fine sandy soil commonly found in agricultural production areas in the region. Laboratory testing indicated that the field capacity of this soil is 6-7% (at 0.10 kPa suction, Calhoun et al., 1974). Daily irrigation events may result in water movement below the root zone even if application is split multiple times during the day. This is important for shallow rooted crops such as bell pepper where most of the roots can be found in the top 20 to 30 cm (Gough, 2001; Keng et al., 1979; Goyal et al., 1988; Morita and Toyota, 1998). On the other hand, the constant relatively high soil moisture content in treatments A2 and A3 may have resulted in reduced yields below those of M2. In addition, a water supply failure on the farm resulted in no irrigation on all plots for more than a week in early June (fig. 1). This may have impacted yield differences as well. Figure 1 presents examples of the soil volumetric moisture content at the 15 and 30 cm depths measured every hour and averaged across three replicates for one manual and one automatic irrigation treatment. Although less irrigation water was applied over the entire season to treatments A2 and A3 than M3 and M4, the result was higher and more stable soil moisture content at the 15 cm depth with similar crop yields. In contrast, large spikes in the soil moisture content can be seen in the daily irrigation events (M1, M2, M3, and M4) and particularly in the highest levels of irrigation water application (fig. 1).

CONCLUSIONS

The highest bell pepper yields were produced with typical manual irrigation of once or twice each day (M2). The next highest yields were produced by M3, M4, A2, and A3. The A2 and A3 automatic irrigation treatments used approximately 50% less water than the M3 and M4 treatments with similar yield results. The high yield results may have been due to excessive soil moisture conditions on the automatic treatments over the season or stress due to a water supply problem in the experiment at the end of the season. Soil volumetric moisture content was maintained at a fairly constant and higher levels than manual irrigation treatments. Water use efficiency was highest on the A2 and A3 automatically irrigated treatments. This first year of data indicate that small frequent irrigation events may reduce the waste of irrigation water while maintaining crop yields compared to producer typical practices (M3 and M4). Additional work is required to repeat these results and to develop ideal soil moisture level settings for automatic irrigation systems. Future research should attempt to repeat these initial results and determine why one manual treatment resulted in the highest yields.

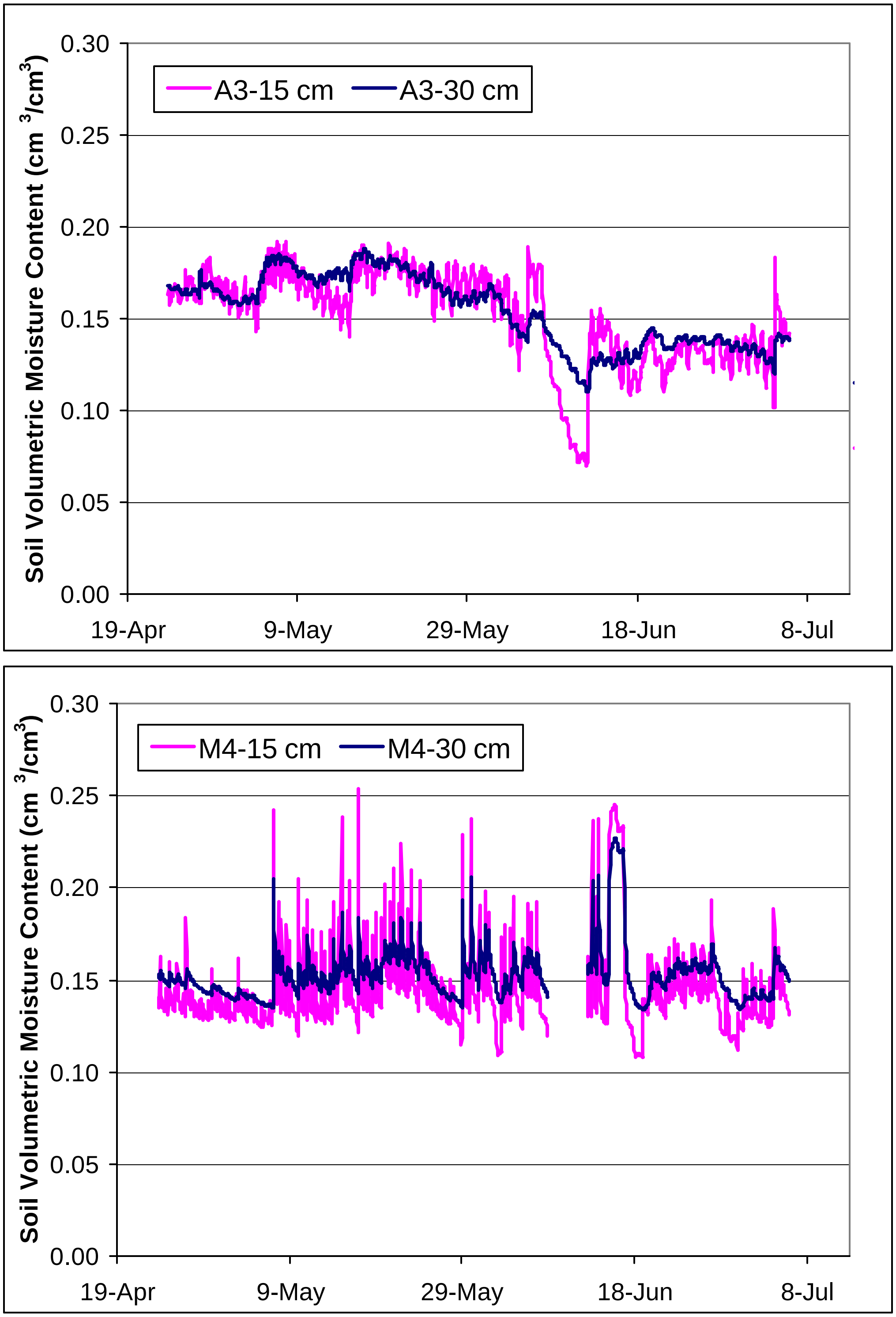

Figure 1. Example of average (across three replicates) hourly soil volumetric moisture content for the automatically initiated irrigation treatments (A3 only) and manual treatments (M4 only).

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