

## **Development of Irrigation and Fertigation Control Using 5TE Soil Moisture, Electrical Conductivity and Temperature Sensors**

Miralles, J.<sup>1</sup>, M.W. van Iersel<sup>2</sup> & Bañón, S.<sup>1,3</sup>

<sup>1</sup>*Departamento de Producción Vegetal  
Universidad Politécnica de Cartagena  
30203 Cartagena-Murcia, Spain*

<sup>2</sup>*The University of Georgia, Department of  
Horticulture, Athens, GA 30602*  
<sup>3</sup>*Unidad Asociada al CSIC  
Horticultura Sostenible en Zonas Áridas*

### **ABSTRACT**

Appropriate irrigation and fertilization is critical to produce good quality plants in a sustainable way. Irrigation can be controlled with capacitance sensor, and this study had the objective of developing a system to control fertilization and irrigation. The system was built using 5TE sensors (Decagon Devices, Inc.) connected to a datalogger (CR10X, Campbell Scientific, Logan, UT). The datalogger was programmed to maintain the substrate (peat-perlite mixture) volume water content ( $\theta_v$ ) at 0.25, 0.30, 0.35, or 0.40  $\text{m}^3 \cdot \text{m}^{-3}$  and the pore water electrical conductivity (PoreEC) at 1, 2, 3, or 4  $\text{dS} \cdot \text{m}^{-1}$  in a factorial desing, thus resulting in 16 treatments. Each treatment had six 15-cm pots with ornamental cabbages (*Brassica oleracea*) and two drippers (one for irrigation with water and the other for fertigation), with the sensor placed in one of the pots. The system was evaluated comparing  $\theta_v$  and PoreEC registries with accurate probes. At the end of the experiment the shoots of the plants were harvested for dry weight measurements. The results showed that control of substrate  $\theta_v$  was good, with substrate  $\theta_v$  generally within 0.03  $\text{m}^3 \cdot \text{m}^{-3}$  of the set point. Control of poreEC was more difficult, and there were large fluctuations in poreEC, especially during the first 20 days of the experiment. The regressions with the data obtained with the accurate probes showed  $r^2$  of 0.62 and 0.28 for  $\theta_v$  and PoreEC, respectively, which confirmed the better control of  $\theta_v$ . PoreEC control was less accurate because of two main reasons: 1) Substrate-electrode contact is critical for proper PoreEC measurements and this was a problem because of the little size of the sensor electrodes. 2) The fertilizer is not distributed as uniformly and quickly as water and needs more time to reach the sensor electrodes. During the 35-day experiment plants received between 0.14 and 3.6 liters of water and 0.26 and 1.15 liters of fertilizer solution depending on the treatment, which affected the plant growth. Shoot dry weight decreased as the set point for poreEC increased. Shoot dry weight was also reduced by low set points for  $\theta_v$ , while shoot dry weights were similar with set points of 0.35 and 0.40  $\text{m}^3 \cdot \text{m}^{-3}$ . So, the results suggest that  $\theta_v$  can be more easily controlled than poreEC although a better contact probe electrodes-substrate could improve this control and the system operation.

## INTRODUCTION

Greenhouse production sustainability is becoming increasingly important. Efficient use of water and fertilizer are important components of sustainable production. We have previously shown that soil moisture sensors can be used effectively to control greenhouse irrigation, assuring that only the amount of water required by the crop is applied (Burnett and van Iersel 2008). The use of soil moisture sensors for irrigation control can greatly reduce the amount of water used; e.g., irrigation water used for *Hydrangea macrophylla* was reduced by 83% when soil moisture sensors were used to control irrigation (van Iersel et al. 2009). Irrigation and fertilization are closely linked in greenhouse production, because fertilizer is commonly applied with the irrigation water in a water-soluble form. In addition, more efficient irrigation reduces leaching of both water and nutrients from the pots (Ristvey et al 2004). Therefore, any change in irrigation practices may necessitate a change in fertilization as well. Ideally, if irrigation is controlled by soil moisture sensors, fertilization would be controlled by sensors that can detect the nutrient status of the substrate. Electrical conductivity (EC) can be used as an indicator of the total amount of soluble salts in the substrate, and as such is commonly used as a proxy for nutrient availability.

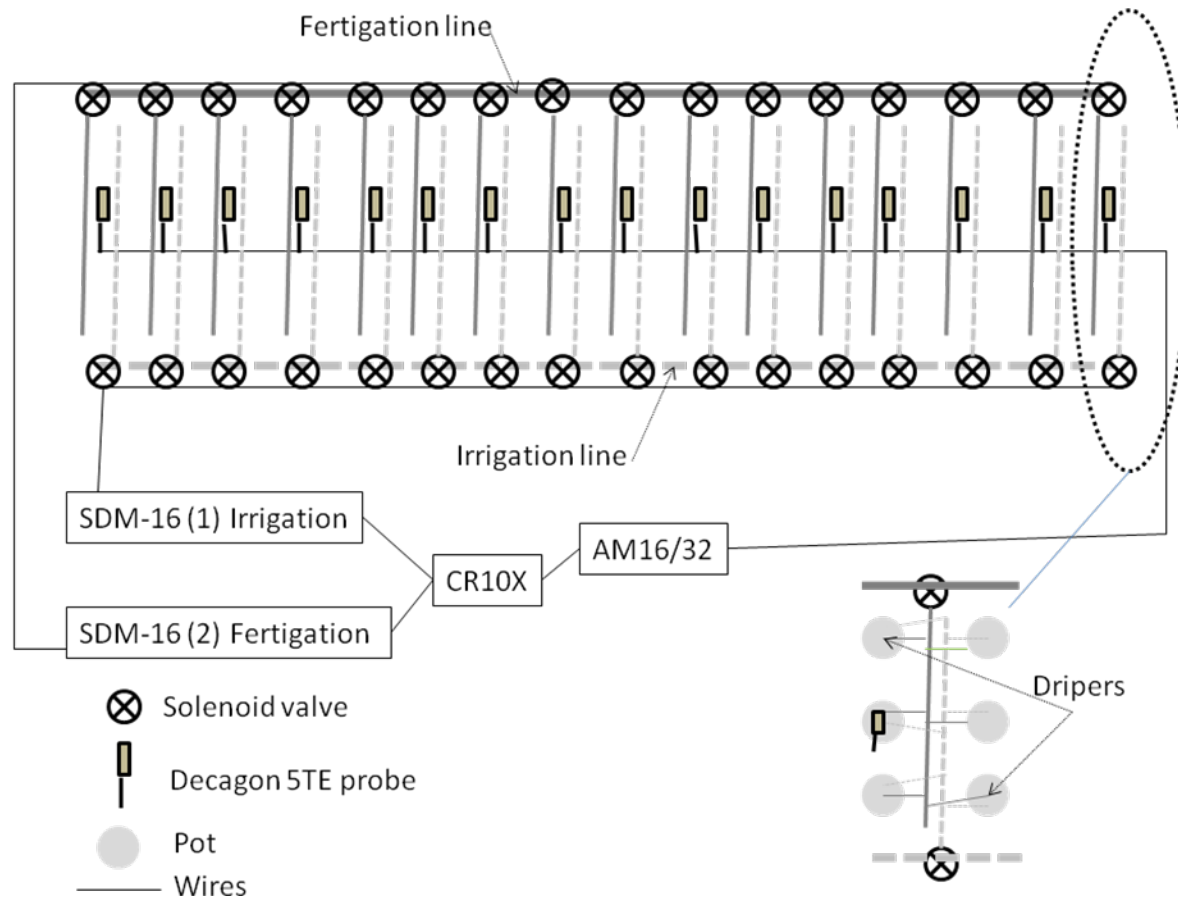
Recently, new sensors (5TE, Decagon Devices, Pullman, WA) have become available that can measure both the volume water content ( $\theta_v$ ) and EC of soilless substrates. Water content measurements with these sensors work the same as with other capacitance sensors that have been on the market for several years, and such capacitance sensors have been used successfully for irrigation control (Burnett and van Iersel 2008, van Iersel et al. 2010, 6). EC measurements are taken using two small stainless steel screws embedded in the sensor. These screws serve as the electrodes for the EC measurements. Thus, EC measurements using these sensors reflect the bulk EC of the substrate; i.e., these measurements reflect how well the substrate as a whole (including the solid substrate components, the pore water in the substrate, and the air in the substrate) conducts electricity. However from a plant's perspective, it is more relevant to determine the EC of the pore water (PoreEC). Hilhorst (2000) described a model that allows the estimation of PoreEC from measurements of bulk EC, temperature and the real portion of the dielectric permittivity of the substrate ( $\epsilon_b$ ) which is measured by the sensors.

The objective of our study was to determine whether these 5TE sensors can be used to control both the water content and the PoreEC of soilless substrates. So, ornamental cabbages were grown in plastic pots filled with a mixture of peat and perlite.

## MATERIAL AND METHODS

An automated irrigation and fertigation system was built using 16 5TE sensors connected to a datalogger (CR10X, Campbell Scientific, Logan, UT), using a multiplexer (AM16/32, Campbell Scientific) (Fig. 1). Sensor readings of  $\epsilon_b$  were converted to the  $\theta_v$  of the substrate, using our own calibration for the peat-perlite mix used in this study ( $\theta_v = -0.0387 \times \epsilon_b^2 + 3.4436 \times \epsilon_b - 4.1848$ ,  $R^2 = 0.99$ ;  $\theta_v$  is expressed here as % water content and was subsequently converted to units of  $\text{m}^3 \cdot \text{m}^{-3}$  by dividing by 100). Bulk EC, temperature, and  $\epsilon_b$  measurements were used to calculate PoreEC, using Hilhorst's equation (Hilhorst 2000), with an offset value (dielectric permittivity of the dry substrate) of 1.55.

The datalogger determined whether the measured  $\theta_v$  was below the  $\theta_v$  set point for a particular plot. If so, the datalogger then compared the calculated PoreEC to the EC set point. If the PoreEC was above the EC set point, the plants were irrigated with tap water, otherwise the plants were fertigated with a fertilizer solution with an EC of approximately  $10 \text{ dS} \cdot \text{m}^{-1}$ . Such a high fertilizer EC was needed to see a detectable increase in PoreEC. The datalogger activated solenoid valves to either irrigate or fertigate each group of plants using two relay drivers (SDM16ACDC, Campbell Scientific). To achieve this, two separate irrigation systems were built, one that provided plants with tap water and another one that provided plants with fertilizer solution (Fig. 1). The plants were irrigated/fertigated using drip emitters connected to pressure compensated emitters ( $2 \text{ L} \cdot \text{hour}^{-1}$ , Netafim, Tel Aviv, Israel). Each time the irrigation/fertigation for a particular plot was activated, the solenoid valve opened for 30 s, thus applying approximately 16.5 ml per irrigation/fertigation event.



**Figure 1.** Diagram of the sensor-controlled irrigation and fertigation system. The CR10X datalogger measures the water content and EC of the substrate using 5TE sensors and then determines whether to irrigate or fertigate a particular plot. Solenoid valves are activated using two relay drivers (SDM16ACDC). Only one out of six pots in each plot has a 5TE sensors. Irrigation and fertigation of all six plants in a plot are controlled based on the readings from that one sensor.

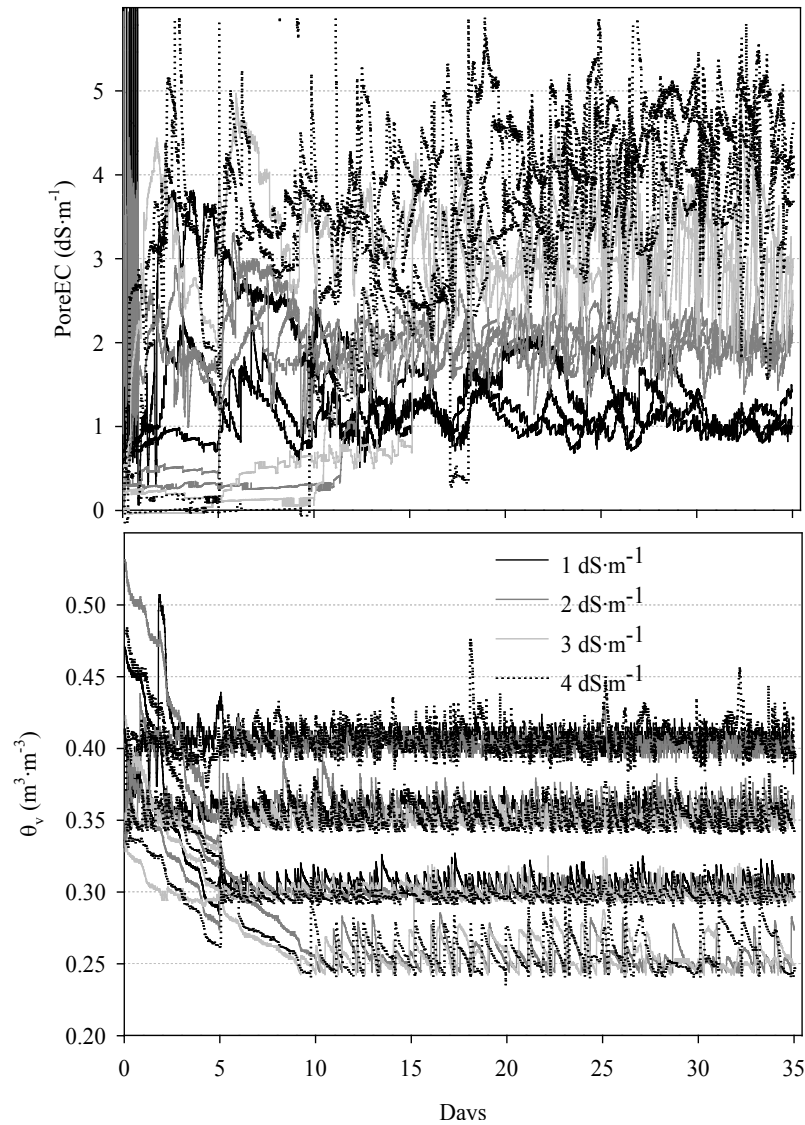
To test the automated irrigation and fertigation system, 96 ornamental cabbages (*Brassica oleracea*) were planted in 15-cm pots filled with a peat-perlite substrate (Fafard 2P, Agawam, MA). The plants were arranged in 16 plots of 6 plants each, and a 5TE sensor was inserted into one of the six pots within each plot. The datalogger was programmed to maintain the substrate water content at 0.25, 0.30, 0.35, or 0.40  $\text{m}^3\cdot\text{m}^{-3}$  and the pore water EC at 1, 2, 3, or 4  $\text{dS}\cdot\text{m}^{-1}$  in a factorial arrangement, thus resulting in 16 treatments. Due to the malfunctioning of one sensor, there are no data from the treatment with set points of 0.40  $\text{m}^3\cdot\text{m}^{-3}$  and 3  $\text{dS}\cdot\text{m}^{-1}$ . Once a week, four measurements per treatment of  $\theta_v$  and EC (bulk and pore) were collected with Theta and Sigma probes (Delta-T Devices, Ltd.)

respectively. The shoots of the plants were harvested at the end of the study for dry weight measurements after 35 days.

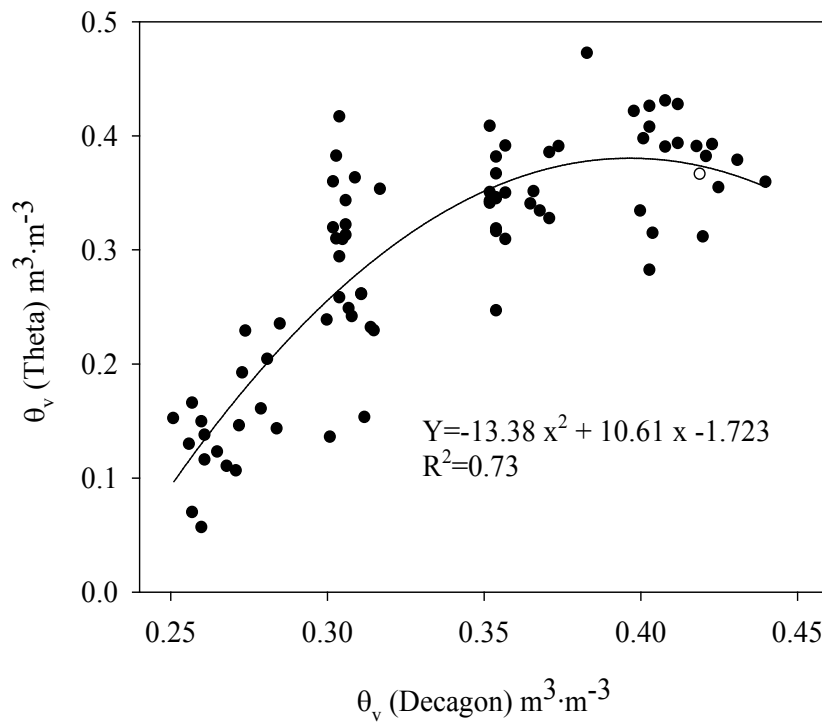
## RESULTS AND DISCUSSION

Control of substrate  $\theta_v$  was good, with substrate  $\theta_v$  generally within  $0.03 \text{ m}^3 \cdot \text{m}^{-3}$  of the set point. Control of PoreEC was more difficult, and there were large fluctuations in PoreEC, especially during the first 20 days of the experiment (Fig 2). The  $\theta_v$  correlation with the Theta probe readings was better than the PoreEC correlation with sigma probe readings ( $r^2 = 0.73$  and  $0.41$ , respectively), which suggests a greater accuracy in  $\theta_v$  than EC measurements (Figs. 3 and 4). Several factors contributed to the pore water EC fluctuations and the lack of PoreEC accuracy. 1) No control of PoreEC was possible until after the  $\theta_v$  of the substrates had reached the  $\theta_v$  set point, since plants were not irrigated or fertigated until this set point was reached. 2) The small screws that serve as EC sensors on the 5TE results in less than optimal contact between the electrodes and the substrate (or pore water). If there is an air pocket surrounding one of the electrodes, the measured bulk EC is low, resulting in a low calculated PoreEC as well. Good contact between the electrodes and the substrate is critical for the bulk EC measurements. Sensors with a different design, including larger electrodes, might therefore work better. 3) The calculated PoreEC depends on the  $\theta_v$  of the substrate, resulting in rapid changes in PoreEC following an irrigation or fertigation event. In addition, as the substrate dries out following irrigation, the PoreEC increases because the solution becomes more concentrated as the amount of water decreases. 4) There is no verification of how accurately the Hilhorst model determines the PoreEC, and recent research has suggested that the Hilhorst model may not be very accurate in soilless substrates (Arguedas-Rodriguez 2009). In addition, the correct offset value in the Hilhorst model is not clear. More work is needed on how to determine PoreEC. 5) Fertilizer appears to move much more slowly through the substrate than water. Preliminary data showed that applying very small amounts of water ( $5.5 \text{ ml} \cdot \text{plant}^{-1}$ ) at a time resulted in increases in measured  $\theta_v$ , but not EC. Fertilizer concentrations were much higher at the location of the emitter applying the fertilizer solution than in the rest of the substrate, which led to spatial variability in PoreEC. This was evident from variability in sigma probe EC readings when the probe was inserted in different positions in the pot. It may take several irrigation/fertigation events to move this fertilizer further into the substrate, where it can be measured by the EC sensor. To address this problem, we increased the amount of water applied at each irrigation, sacrificing some precision in control of  $\theta_v$ . Despite these issues, there were clear differences in the PoreEC among the different EC

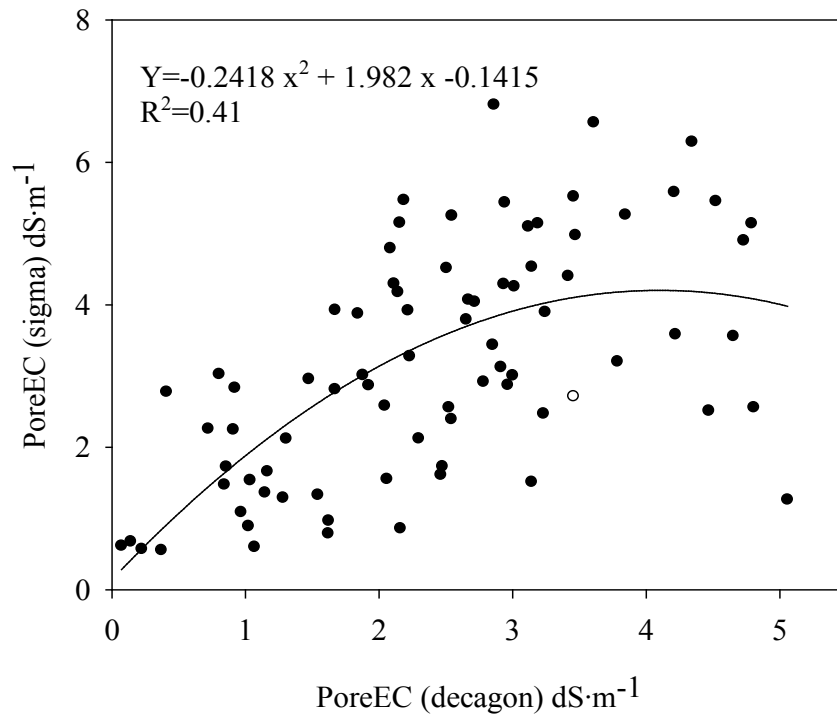
set points, and this was most evident during the last 15 days of the study. This suggests that the use of EC sensors for fertigation control is possible, but better sensors may be needed to get better measurements and control of PoreEC.



**Figure 2.** PoreEC (top) and  $\theta_v$  (bottom) of the substrate throughout the experiment. Set points for PoreEC were 1, 2, 3, and 4 dS·m<sup>-1</sup>, and those for substrate water content were 0.25, 0.30, 0.35, and 0.40 m<sup>3</sup>·m<sup>-3</sup>. Note that control of substrate water content was better than control of pore water EC.



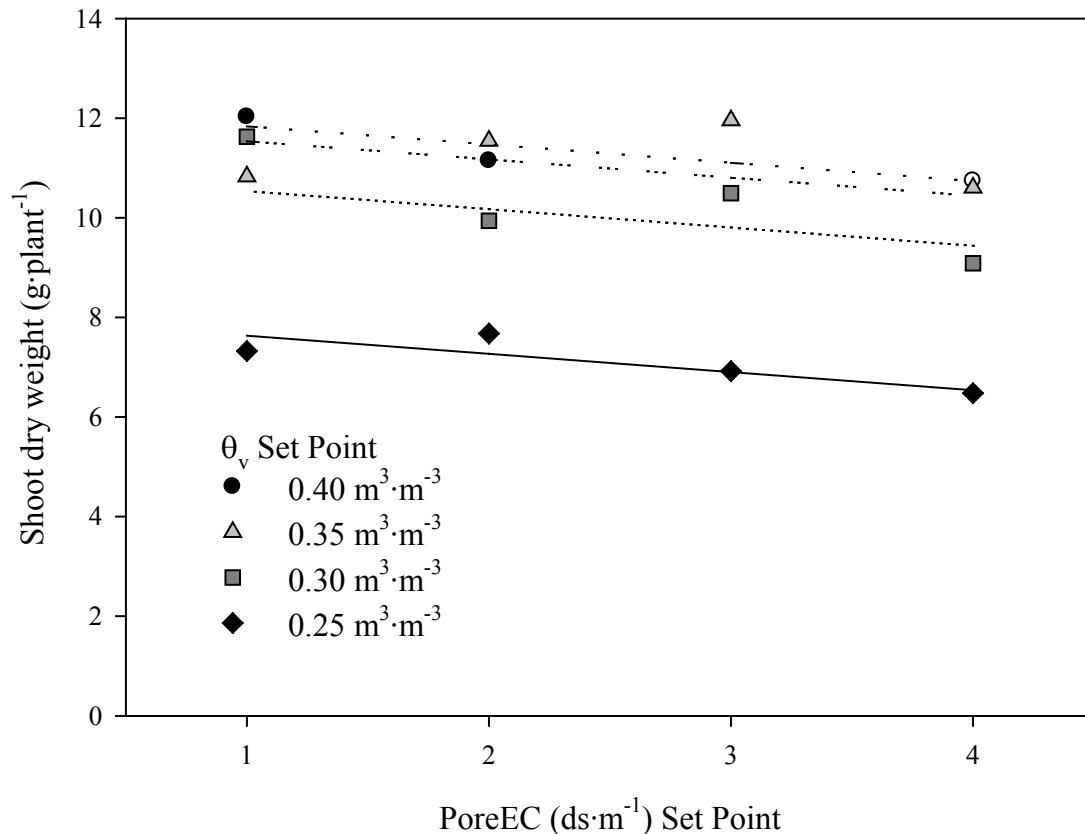
**Figure 3.** Analysis of regression between  $\theta_v$  measurements using a Theta probe and 5TE probes.



**Figure 4.** Analysis of regression between PoreEC measurements using a Sigma probe and 5TE probes.

Depending on the treatment, the plants received between 0.14 and 3.6 liters of water and 0.26 and 1.15 liters of fertilizer solution during the 35-day experiment. For example, the plants in the treatment with set points of  $1 \text{ dS}\cdot\text{m}^{-1}$  and  $0.40 \text{ m}^3\cdot\text{m}^{-3}$  received 0.40 liters of fertilizer solution and 3.6 liters of water, while set points of  $4 \text{ dS}\cdot\text{m}^{-1}$  and  $0.30 \text{ m}^3\cdot\text{m}^{-3}$  resulted in applications of 1.15 liters of fertilizer solution and 0.35 liters of water during the experiment.

Both  $\theta_v$  and PoreEC set points affected the growth of the plants (Fig. 5). Shoot dry weight decreased as the set point for pore water EC increased. Shoot dry weight also was reduced by low set points for  $\theta_v$ , while shoot dry weights were similar with set points of  $0.35$  and  $0.40 \text{ m}^3\cdot\text{m}^{-3}$ . Such effects of  $\theta_v$  on plant growth are consistent with earlier findings (Burnett and van Iersel 2008, van Iersel et al. 2010).



**Figure 5.** The effect of set points for substrate  $\theta_v$  and PoreEC on the shoot dry weight of ornamental cabbage. There was a linear effect of pore water EC and a quadratic effect of substrate volumetric water content on shoot dry weight, but no interactive effect between PoreEC and  $\theta_v$  (Dry weight =  $-30.5 - 0.366 \times \text{EC} + 234 \times \theta_v - 320 \times \theta_v^2$ ,  $R^2 = 0.92$ ,  $P < 0.0001$ ).



## CONCLUSIONS

This is a novel irrigation/fertigation system to control  $\theta_v$  and fertigation, what can be useful for nurseries production to economize both water and fertilizer. However, the fertigation control was difficult mainly because of bad substrate-probe electrode contact. So, to improve this system new probes with better substrate-electrode contact are needed.

## ACKNOWLEDGEMENT

This work was funded in part by USDA-NIFA-SCRI Award no. 2009-51181-05768, CICYT projects (CICYT AGL2008-05258-CO2-1-AGR and CICYT AGL2008-05258-CO2-2-AGR), SENECA project (08669/PI/08) and by the CARM-Program (UPCT-CEBAS-IMIDA 2008). Plant material was donated by Speedling (Blairsville, GA), substrate was donated by Fafard (Agawam, MA), and sensors were donated by Decagon Devices (Pullman, WA).

## LITERATURE CITED

- Arguedas-Rodriguez, F.R. 2009. Calibrating capacitance sensors to estimate water content, matric potential, and electrical conductivity in soilless substrates. University of Maryland, MS Thesis. 118p.
- Burnett, S.E. and M.W. van Iersel. 2008. Water use efficiency and morphology of *Gaura lindheimeri* 'Siskiyou Pink' grown in capacitance sensor controlled irrigation. HortScience 43:1555-1560.
- Hilhorst, M.A. 2000. A pore water conductivity sensor. Soil Sci. Soc. Amer. J. 64:1922-1925.
- Ristvey, A.G., J. D. Lea-Cox and D.S. Ross. 2004. Nutrient uptake, partitioning and leaching losses from container-nursery production systems. Acta Hort. 630:321-328.
- van Iersel, M.W., S. Dove, J.G. Kang, and S.E. Burnett. 2010. Growth and water use of petunia as affected by substrate water content and daily light integral. HortScience (in press).
- van Iersel, M., R.M. Seymour, M. Chappell, F. Watson, and S. Dove. 2009. Soil moisture sensor-based irrigation reduces water use and nutrient leaching in a commercial nursery. Proc. SNA Research Conf. 54:17-21.