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Using soil bulk electrical conductivity to manage saline irrigation in the production of potted poinsettia

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ABSTRACT

Monitoring root substrate electrical conductivity (EC) is critical for the better management of irrigation water and the effective control of soil salinity. The availability of soil moisture sensors that are also capable of measuring permittivity, temperature and soil bulk EC (EC_B), such as the Hydra Probe II (HPII, Stevens W.M.S. Inc.), has opened up new possibilities for the automatic control of saline water irrigation schemes. From such measurements, models have been developed relating the EC_B to pore water EC (EC_{PW}), because the latter is the EC that directly affects the plant. However, previous results have shown that the variability of the HPII-sensor output increases with increasing salinity, affecting the accuracy and reliability of the estimation of EC_{PW}. The purpose of this paper was to assess whether the measurements of the EC_B in saturated substrate can be used to maintain different substrate saline levels, given that EC_B is a function of both water content and EC_{PW}. The greenhouse study evaluated the growth and physiological status of potted poinsettia irrigated with a saline solution (4.5 dS m^{-1}), according to three EC_B thresholds (1.5, 2 and 2.5 dS m^{-1}). In each treatment, when the EC_B threshold was exceeded, the supply of irrigation water was doubled (flushing). Damage to plants increased (lower bract area, aerial part DW and evapotranspiration) as the EC_B threshold increased. Therefore, despite not being a real reading of the soil solution salinity, it is a closely related parameter, which can be regarded as a useful tool for mitigating the negative effects of saline irrigation in the production of potted ornamental plants.

1. Introduction

Because many floriculture crops are salt-sensitive, growers have traditionally used high-quality water for irrigation. However, the availability such water is decreasing through competition between users, which is forcing growers to use low quality water (especially saline water) to irrigate ornamental crops. Salinity reduces growth, alters development and causes leaf damage; as a result, the aesthetic value of ornamental plants is reduced. These effects are accompanied by metabolic dysfunction, including a decreased photosynthetic rate and changes in enzymatic activity (Azza et al., 2007).

Poinsettia, which is inextricably associated with the Christmas season, is one of the most popular flowering potted plants in the world. Due to its long history of cultivation and popularity, a vast library of information exists on its breeding, propagation, growth control, irrigation, nutrition, diseases and pests, and postproduction care and handling (Ecke et al., 2004). However, little is known about the use of probes to control saline irrigation. Poinsettia is considered a salt-sensitive plant (Wu and Dodge, 2005), and its cultivation problems increase rapidly as the water quality deteriorates. Usually, a water source with an electric conductivity (EC) reading of 1.5 dS m^{-1} or less is considered desirable for poinsettia. Ecke et al., 2004 suggested that it is not advisable for the fertigation solution to exceed an EC of 3 dS m^{-1}, while Cavins et al., 2000 indicated that optimum substrate EC values are between 2.8 and 4.1 dS m^{-1} during active growth in poinsettia. Hence, to produce commercial poinsettias under saline irrigation, agronomical measures must be taken to reduce the negative effects of salinity. Among these, irrigation management may affect plant responses to salinity stress.

Irrigation is about water and salt, and measuring the soil EC is a good way to determine the salt content. Many sensors, including the Hydra Probe II (HPII), can measure bulk soil EC (EC_B), the EC of the water, soil and air combined. However, since EC_B increases with the water content, it does not provide good enough insight to help

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manage irrigation. In contrast, pore water EC (EC_{PW}) is a good measurement of salinity and crop response because it is the EC "felt" by the plant. To determine the relationship between EC_B and EC_{PW} several methods and models have been developed in recent years (Rhoades et al., 1990; Hilhorst, 2000; Muñoz-Carpena et al., 2001 and Regalado et al., 2007). However, several factors may affect the reading of probes, one of them being the EC of the soil solution (Campbell, 2002 and Seyfried and Murdock, 2004). Bittelli, 2011 indicated that the accuracy of *in situ* measurements using dielectric sensors in saline soils is still problematic. Valdés et al., 2012 identified a salinity effect on the HPII-sensor permittivity readings, with increasing data scatter as salinity increased, which affected the accuracy and reliability of the estimation of EC_{PW}.

Malicki and Walczak, 1999 and Amente et al., 2000 found a significant relationship between the EC_B and its water content under different levels of salinity (EC_B increasing with increasing θ), the slope being dependent on the level of salinity (the higher the salinity, the steeper the slope). These last authors also found that the EC_B at a constant θ is linearly related to EC_{PW}, with the slope increasing with increasing θ. Incrocci et al., 2009 observed that the EC_B was best related with EC_{PW} at high θ values. From these results, it can be deduced that in a saturated substrate, the values of EC_{PW} and EC_B would be closer than in a drier substrate. Therefore, when substrate moisture is very high, the EC_B could be considered more reliable for evaluating soil salinity and an alternative to EC_{PW} when this cannot be estimated accurately (due to high salinity).

The objective of this study was to evaluate whether the use of EC_B recorded by a HPII sensor can serve to maintain different levels of substrate salinity in potted poinsettia irrigated with saline water. To this end, we studied the effect of three irrigation programmers (based on the establishment of three EC_B thresholds that decide the amount of water to be applied) on growth, development, gas exchange, water status, applied water and substrate and leachate salinity.

2. Materials and methods

2.1. Plant material and culture conditions

Plants of six week old poinsettias (*Euphorbia pulcherrima* Willd. ex Klotzsch) cv. Classic Red (Ecke Europe APS) were transplanted to 2.5 L PVC pots (19 cm Φ) in the last week of September 2011. The pots were filled with a growing medium containing white peat (70%) and coconut fibre-bark (30%). The available water and field capacity of the growing substrate were 38% and 58%, respectively. The study was conducted in a greenhouse at the Agricultural Experimental Station of the Technical University of Cartagena (37° 35′ N, 0° 59′ W), using four crop tables. Thirty-two pots were arranged on each of the tables in four rows of eight pots. The duration of the experimental period was eight weeks.

A datalogger (HOBO H08-004-02, MicroDAQ.com, Ltd., Contoocook, NH, USA) was used to measure air temperature and humidity with a Temperature/RH Smart Sensor S-THB-M008 (MicroDAQ.com, Ltd., Contoocook, NH, USA). Data were collected at 60 s intervals and averages were recorded every 30 min. Weather conditions were $6.02 \pm 3.21\,^{\circ}C$ (minimum) and $30.34 \pm 4.81\,^{\circ}C$ (maximum); minimum relative humidity was $69.92 \pm 9.23\%$ and the maximum $96.90 \pm 3.55\%$.

2.2. Irrigation treatments

The experiment comprised four irrigation treatments: (a) application of fresh water; (b) use of saline water with flushing when an EC_B of 1.5 dS m^{-1} was exceeded ($T_{1.5}$); (c) application of saline water with flushing when an EC_B of 2 dS m^{-1} was exceeded (T_2); (d) application of saline water with flushing when an EC_B of 2.5 dS m^{-1} was exceeded ($T_{2.5}$). The fresh water EC was 1.5 dS m^{-1} and the saline water 4.5 dS m^{-1} (including fertilizer). The volume of water applied per irrigation event was around 450 mL in all treatments, a volume calculated to attain about 25% leaching during irrigation in the control treatment. For flushing, the volume of irrigation water was doubled.

The irrigation was controlled by a system similar to that described by Nemali and van Iersel, 2006 but using a CR1000 data logger; the soil moisture level was measured by a Hydra Soil Moisture Probe (Stevens Water Monitoring Systems Inc., Beaverton, OR) and an Agrónic 4000 (Sistemes Electrònics PROGRÉS, S. A., Bellpuig, Spain) was used to control four pumps connected to four 1000 L tanks which contained the different irrigation solutions. Each pot had two emitters (2 L h^{-1}) connected to a spaghetti tube. The pressure-compensated drip emitters used were tested for homogeneity before the experiment started (the water flow varied between 1.9 and 2.1 L h^{-1}). The HPII sensor (length 12.4 cm; diameter 4.2 cm) was placed vertically in the northwest-facing part of the substrate (between the two emitters in the pot) and was fully inserted into the substrate. The CR1000 was programmed to collect data every minute of three HPII probes per treatment, and to calculate the average every 30 min (ninety data) and the standard error per treatment. The θ was obtained from the electrical permittivity (σ) readings of the soil moisture sensor using our own substrate-specific calibration ($\theta = -0.000231\sigma^2 + 0.02331\sigma + 0.04449$, $r^2 = 0.97$) determined using the procedure described by Valdés et al., 2012. Half an hour after each flushing or irrigation event, the CR1000 was programmed to store the average EC_B of the following ten measurements (EC_{BAI}). Irrigation took place when the average θ of each treatment reached the threshold of 0.40 $m^3\ m^{-3}$, meaning a 47% reduction in the substrate available water; then, if the EC_{BAI} exceeded the EC_B threshold, flushing was applied. The datalogger was programmed to record the number of irrigation and flushing events.

Fertilisation was carried out by the irrigation head, and nutrients were provided at constant concentrations in the irrigation water, containing 80 N-40 P_2O_5-80 K_2O (ppm) at pH 6. This nutrient solution was made by mixing KNO_3, NH_4NO_3, $K(HPO_4)$ and HNO_3. The fertilizers added increased EC by approximately 0.5 dS m^{-1}. Therefore, the EC in the control was 1.5 dS m^{-1} and 4.5 dS m^{-1} in the saline treatments. The ion concentrations in mg L^{-1} in the irrigation saline solution (including fertilizer) were: Na^+ (745), K^+ (66), Ca^{2+} (91), Mg^{2+} (51), chloride (1069), sulfate (297), carbonates (<5), bicarbonate (73), nitrates (239), ammonia (30), phosphate (68), boron (0.38), manganese (0.43), iron (0.92) and zinc (0.12). Fresh water (including fertilizer) had the following ion concentrations in mg L^{-1}: Na^+ (68), K^+ (63), Ca^{2+} (94), Mg^{2+} (49), chloride (92), sulfate (216), carbonates (<5), bicarbonate (73), nitrates (264), ammonia (27), phosphate (77), boron (0.39), manganese (0.42), iron (1.2) and zinc (0.16).

2.3. Measurements

At the end of the experiment (in the third week of November 2011), plant height, plant width, the number of green leaves, the number of bracts, the number of inflorescences, the dry weight (DW) of leaves, the DW of bracts and the stem DW were determined in six plants per treatment. To calculate the DW, the plant respective parts were introduced in clearly identified envelopes and placed in a natural convection bacteriological stove (model 2002471, JP Selecta SA, Barcelona, Spain) at 60 °C until constant weight was reached. Finally, the DW was determined by weighing with a GRAM ST precision balance (sensitivity of 10 mg and up to 1200 g, Gram Precision SL, Barcelona, Spain). The bract area