Available online at www.sciencedirect.com
ScienceDirect
Scientia Horticulturae 110 (2006) 292–297
SCIENTIA HORTICULTURAE
www.elsevier.com/locate/scihorti

An automated system for controlling drought stress and irrigation in potted plants

Krishna S. Nemali, Marc W. van Iersel *

Horticulture Department, 1111 Miller Plant Sciences Building, University of Georgia, Athens, GA 30602, United States

Received 14 February 2006; received in revised form 3 July 2006; accepted 10 July 2006

Abstract

Efficient, automated irrigation systems, which can irrigate the substrate of potted plants to a desired level and supply those plants with just the amount of water required for normal plant growth are currently not available. These systems, if developed, could reduce wastage of irrigation water due to excess application. This subsequently could reduce leaching and run-off, and aid growers to cope with increasing regulations of water-use by state governments in the US. Here we describe an irrigation controller that irrigates a substrate to a set-point (volumetric water content, θ) and maintains θ close to that set-point for several weeks. The controller uses calibrated, dielectric moisture sensors, interfaced with a datalogger and solenoid valves, to measure the θ of the substrate every 20 min. When the θ of the substrate drops below the set-point, the controller opens a solenoid valve, which results in irrigation. The θ of the substrate is maintained near a constant level as the datalogger is programmed to increase θ by only 2–3% during each irrigation. Using this controller with bedding plants, we were able to maintain four distinct levels of θ for a prolonged period (40 days), regardless of changes in plant size and environmental conditions. The daily average θ maintained was slightly higher (within 2–3% on any particular day) than the set-point. When the θ measured and maintained by the dielectric moisture sensors was tested using measurements with another probe placed in the same container, the θ measured by both probes was found to be similar, indicating that the controller can indeed maintain θ near the target level. This controller may also have applications in stress physiology, since it allows control over the rate at which drought stress is imposed on plants.

Keywords: Automated irrigation control; Bedding plants; ECH_2O dielectric sensor; Evapotranspirational water-use; Greenhouse production; Irrigation system; Leaching

1. Introduction

Increased labor costs, stricter environmental regulations, and increased competition for water resources from urban areas provide strong motivation for greenhouse and nursery growers to opt for more efficient irrigation systems. Benefits of such systems include reductions in both labor costs and water wastage. Overhead irrigation systems like sprinkler-, boom-, and drip-irrigation, and subirrigation systems like ebb-and-flow and flooded floor irrigation are easily automated. Thus, these systems can reduce labor costs related to irrigation, with subirrigation systems having an additional advantage of minimizing leaching losses from the substrate (Elliot, 1990; Yelanich and Biernbaum, 1990; van Iersel, 1996; Morvant et al., 1997; Uva et al., 1998). However, a potential weakness of these automated systems is their inability to irrigate a substrate to a desired moisture level or in the minimal amounts needed for normal growth.

Automated irrigation systems are commonly run by controllers set to a pre-determined irrigation schedule (e.g. to run at a particular time of the day and for a particular duration) and not based on actual measurements of θ. Often, automated systems irrigate the substrate close to saturation regardless of plant water requirement and result in wastage of good quality irrigation water through leaching and run-off. To minimize water wastage from automated irrigation systems, there is a need to develop improved irrigation controllers, which can irrigate the substrate to a desired θ. Such controllers will aid greenhouse growers to comply with stricter government regulations on water-use and fertilizer run-off.

An irrigation controller, which can wet the substrate to a desired level also will be useful in research on plant water relations. The inability to maintain θ at a desired level imposes a limitation in physiological experiments related to studying

* Corresponding author. Tel.: +1 706 583 0284; fax: +1 706 542 0624.
E-mail address: mvanier@uga.edu (M.W. van Iersel).

0304-4238/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.scienta.2006.07.009

water requirements of plants. To study plant responses to different θ levels, experiments in the field of plant water relations often are conducted by manually maintaining these θ levels. This method commonly involves weighing the containers daily and replenishing the fraction of water lost in transpiration (Sinclair and Ludlow, 1986; Ekanayake et al., 1993; Ray and Sinclair, 1998). This method is labor-intensive and in addition, changes in plant fresh mass are generally neglected in calculations of evapotranspiration. In other studies, to overcome the intensive labor of the previously-described technique, plant responses to substrate water content are studied by withholding irrigation and studying responses as the substrate water content decreases. This also is not an ideal method as the rate at which drought stress develops after withholding water is usually faster in containers (due to the smaller volume of available water) than under natural conditions and is not controlled. Observed physiological responses in plants can be different for a rapidly-imposed and slowly-imposed drought stress (Cornic et al., 1987; Ludlow, 1987; Saccardy et al., 1996; Earl, 2003).

With both methods, it is not possible to have precise control over the rate at which drought stress is imposed (Earl, 2003). Irrigation controllers that allow better control of θ may make it possible to study plant responses at distinct and precisely-controlled levels of θ.

Here, we describe an irrigation controller that can be used to irrigate and maintain substrates close to a desired θ for prolonged periods. Irrigation is controlled by a datalogger, which uses dielectric moisture sensors, a relay driver, and solenoid valves to irrigate and maintain substrates close to a desired level. This system can be used to either control the rate at which drought stress is imposed, or to maintain θ at distinct levels. This system has many potential applications in horticultural production and research.

The objectives of this study were:

(i) to test whether the controller can maintain the θ of substrates at a constant level and close to a set-point for a long period and within an acceptable range of the targeted value,
(ii) to test whether fluctuations in greenhouse environment and variations in plant size affect the performance of the controller to irrigate and maintain substrates close to a desired θ level, and
(iii) to test the accuracy of θ maintained in substrates by the controller.

2. Materials and methods

2.1. Irrigation system

The layout of the irrigation system is shown in Fig. 1. Frequent measurements of the θ of the substrate were accomplished using calibrated [$\ln(\theta) = -6.99 + 16V - 9.9V^2$, $R^2 = 0.91$] dielectric soil moisture sensors (ECH_2O-10 probes, Decagon, Pullman, WA, USA). A total of 16 ECH_2O moisture sensors were used in the study. The ECH_2O moisture sensors were connected in a single-ended fashion to a multiplexer (AM25T, Campbell Sci., Logan, UT, USA), which in turn was connected to a datalogger (CR10X, Campbell Sci.) to measure the sensor output. Type-T thermocouples were used to measure the temperature of the substrate. The thermocouples were connected to the multiplexer as well. The datalogger was programmed to automatically measure ECH_2O probe output once every 20 min, and to calculate and compensate θ for changes in substrate temperature based on a pre-determined relationship between substrate temperature and probe output. The voltage output from the probes increases by 1.88 mV per °C, or approximately 0.002–0.003 $m^3\ m^{-3}$ water content per °C (Nemali and van Iersel, 2006). Here we used a temperature correction of 0.003 $m^3\ m^{-3}\ °C^{-1}$. To do this, the difference between the temperature at which the probes were calibrated (23.2 °C) and the measured substrate temperature was calculated. Subsequently, for every °C difference, 0.003 $m^3\ m^{-3}$ was added to (for substrate temperatures <23.2 °C) or subtracted from θ, as calculated from the above calibration equation. Although we used ECH_2O-10 probes, other soil moisture probes could be used as well. Based on preliminary data, suitable probes include ThetaProbes (delta T, Cambridge, UK), ECH_2O-5 and ECH_2O-TE probes (Decagon). These three probes have the advantage that they are less sensitive to substrate EC and temperature, and temperature corrections may not be necessary for these probes (our unpublished results).

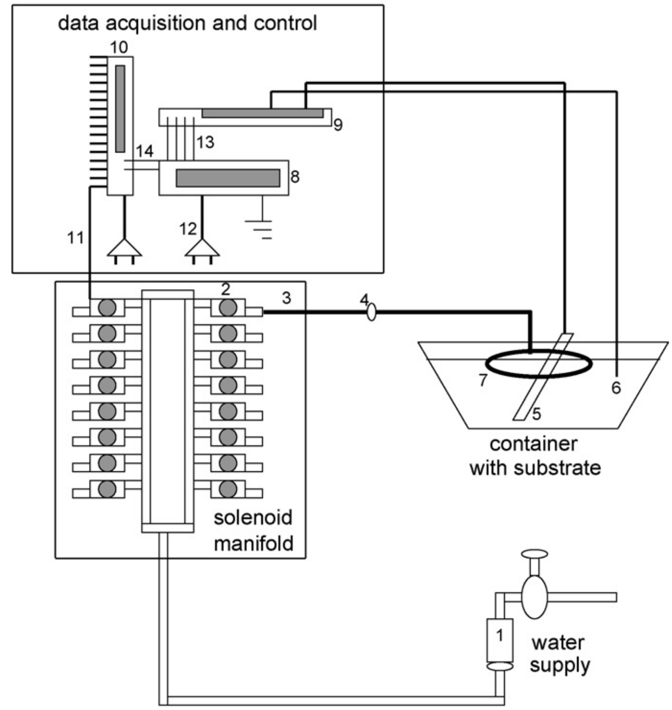

Fig. 1. Schematic diagram showing various parts of the irrigation system. (1) Pressure regulated water source; (2) solenoid valve; (3) outlet tubing; (4) pressure-compensated emitter; (5) ECH_2O sensor; (6) thermocouple; (7) drip emitter (ring); (8) CR10X datalogger; (9) AM25T multiplexer; (10) SDM-16AC/DC controller (relay driver); (11) power supply to solenoids; (12) to main power supply; (13) connecting wires between CR10X and AM25T; (14) connecting wires between CR10X and SDM-16AC/DC controller. Only one container is shown in detail although 16 independent groups of plants can be irrigated.