Scientia Horticulturae 179 (2014) 132–139

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Comparing substrate moisture-based daily water use and on-demand irrigation regimes for oakleaf hydrangea grown in two container sizes

Ethan Hagen[a], Susmitha Nambuthiri[b], Amy Fulcher[c,*], Robert Geneve[b]

[a] Department of Plant Sciences, University of Tennessee, 2431 Joe Johnson Drive, rm. 252 PSB, Knoxville, TN 37996-4561, USA
[b] Department of Horticulture, University of Kentucky, 401b Plant Science Building, Lexington, KY 40546-0091, USA
[c] Department of Plant Sciences, University of Tennessee, 2431 Joe Johnson Drive, rm. 252 PSB, Knoxville, TN 37996-4561, USA

ARTICLE INFO

Article history:
Received 31 May 2014
Received in revised form 31 August 2014
Accepted 2 September 2014
Available online 29 September 2014

Keywords:
Water deficit
Capacitance sensors
Nursery crops
Photosynthesis

ABSTRACT

Independently controlled irrigation plots were designed to test two container nursery irrigation regimes on oakleaf hydrangea (*Hydrangea quercifolia* 'Alice') in both nursery and controlled greenhouse environments. The experiments were conducted in both 3.8 and 11.4 L containers. Plants were automatically irrigated by one of two soil moisture sensor-based regimes: (1) a daily water use (DWU) system that delivered the exact amount of water that had been lost in the previous 24 h and (2) an on-demand (OD) irrigation system based on a specific substrate moisture content derived from the relationship between substrate moisture and photosynthetic rate. In this system, irrigation was applied when the substrate moisture level fell below 33% container capacity, which corresponded to 90% maximum predicted photosynthetic rate. Both treatments delivered the volume of water required to return the containers to container capacity by overhead irrigation, but the DWU system was static, irrigating once per day, whereas OD was dynamic and irrigated whenever the substrate moisture reached the 33% threshold level. Gas exchange was measured at the driest point prior to the next irrigation event. Periodical growth index, water use, and final dry weight were recorded. OD used less water than DWU outdoors, reduced leaching fraction among greenhouse experiments, and had either no or a positive impact on biomass in all but one trial. For 3.8 L plants, photosynthesis and stomatal conductance were consistently greater when irrigated by the OD program. Both treatments used significantly less water than the industry standard of 2.5 cm per day. This research demonstrated that both DWU and OD are a dramatic improvement over conventional irrigation scheduling and could be adopted as conservative irrigation systems for nursery production.

1. Introduction

Water scarcity is a growing concern across the globe and is projected to become more severe due to increases in population growth, urbanization, and per capita consumption as well as changing water availability due to climate change (Food and Agricultural Organization of the United Nations, 2007). Irrigation withdrawals account for over 70% of all freshwater used (Food and Agricultural Organization of the United Nations, 2007) and produce over 40% of the world's food supply (Turral et al., 2011). This shows the vulnerability of agriculture to water scarcity, but it also highlights how improvements in irrigation could have a large impact on reducing overall agricultural water use and preventing water scarcity. Nursery irrigation is particularly inefficient and modifying irrigation practices is necessary as legislation continues to restrict water use (Ackerman and Stanton, 2011; State of Oregon, 2013).

Substrate moisture sensors (SMS) have emerged as a mechanism for implementing precision irrigation in intensive agriculture. SMS measure real time substrate moisture status, whenever a preset threshold water content is reached, an irrigation controller calculates the timing, amount and duration of irrigation required to replenish the water in a growing substrate to a preset level (generally container capacity) as evaluated in *Hydrangea quercifolia* 'Alice' (Hagen, 2013) and in *H. macrophylla* 'Fasan' and *Gardenia jasminoides* 'Radicans' (O'Meara et al., 2014). SMS can be used to align irrigation scheduling with evapotranspiration, substrate water storage changes, and rainfall in container production environments (Lea-Cox et al., 2013) and can greatly reduce irrigation water use compared to the standard practice of static, timer-based irrigation without risking adverse consequences from under- or

* Corresponding author. Tel.: +1 865 974 7152; fax: +1 865 974 1947.
E-mail addresses: ehagen1@utk.edu (E. Hagen), Susmitha.Nambuthiri@uky.edu (S. Nambuthiri), afulcher@utk.edu (A. Fulcher), rgeneve@uky.edu (R. Geneve).

http://dx.doi.org/10.1016/j.scienta.2014.09.008
0304-4238/

overwatering resulting in fertilizer savings as well as water and water delivery, e.g., pump and valve operation, savings (Majsztrik et al., 2013).

Using static timers for control does not account for day-to-day changes in plant water requirements, often over-irrigating and reducing water use efficiency compared to calculating and returning the substrate to container capacity (Warsaw et al., 2009). Warsaw et al. (2009) used manual substrate measurements to calculate and apply the water lost the previous day resulting in a 27–70% decrease in water use without impacting plant growth on a range of taxa. A commercially acceptable irrigation system that would provide similar benefits would need to be developed using the following guidelines. It must be: (1) simple; (2) automated; (3) easily configured to a large number of crops; (4) accurately estimate water use to prevent over and under irrigation (thus conserving water and minimizing fertilizer and pesticide leaching); and (5) not increase production time compared to current irrigation scheduling (Fulcher et al., 2012).

The system developed by Fulcher et al. (2012) and examined in this experiment would be the first physiologically based system for container nursery crops that automates both aspects of precision irrigation scheduling: timing of irrigation and volume of water needed. The objective of this experiment was to compare a physiologically-based, on-demand irrigation regime with a daily water use replacement regime: Irrigating plants when they reach a certain dryness threshold based on the relationship between photosynthesis and substrate moisture content regardless of time of day (on-demand), and replacing water lost in the previous 24 h at a specified time (daily water use).

2. Materials and methods

2.1. Experiment locations

This research consisted of a series of experiments testing physiologically-based and daily water use irrigation systems, as described below, in both outdoor nursery and controlled environment settings. All trials tested these irrigation systems on Alice oakleaf hydrangea (*H. quercifolia* Bartr. 'Alice'). Two container sizes (3.8 L and 11.4 L) were used; 3.8 L were used in Lexington, Kentucky, United States (38.105°N, −84.486°W) and 11.4 L were used in Knoxville, Tennessee, United States (35.946°N, −83.939°W). Trials were conducted in nursery and greenhouse production settings in both locations.

2.2. Irrigation systems, plot description

Root proliferation was periodically monitored in a cohort of plants that were not included in the experiment to determine root establishment. Plants were hand watered until roots reached the container sidewall. Once the roots reached the sidewall, irrigation was controlled by an automated system. Substrate moisture levels were measured and controlled using dielectric capacitance sensors (ECHO-5, Decagon Devices Inc., Pullman, WA, USA) connected to a datalogger (CR1000, Campbell Scientific Inc., Logan, UT, USA) with a multiplexer (AM16/32, Campbell Scientific Inc., Logan, UT, USA) and a 16-channel relay controller (SDM-CD16AC, Campbell Scientific Inc., Logan, UT, USA) to operate solenoid valves. Volumetric water content (VWC) values were calculated from mV output and sensor-specific calibration equations in the program (Hagen, 2013). One capacitance sensor per container was installed halfway between the center of the container and the container sidewall. Sensors were oriented vertically with the broad side of the sensor facing the plant stem and inserted into the substrate so that the sensor overmold/wire junction was 2.5 cm below the surface of the substrate. The VWC of each irrigation zone was calculated by averaging values from three sensors per zone. The datalogger measured VWC every minute and recorded 15-min averages. Water use over the course of the experiment was calculated for each zone based on the amount of time each solenoid remained open and the flow rate, calculated by measuring the volume of water captured in pans during timed trials. A rain gauge was wired to the datalogger for local precipitation data.

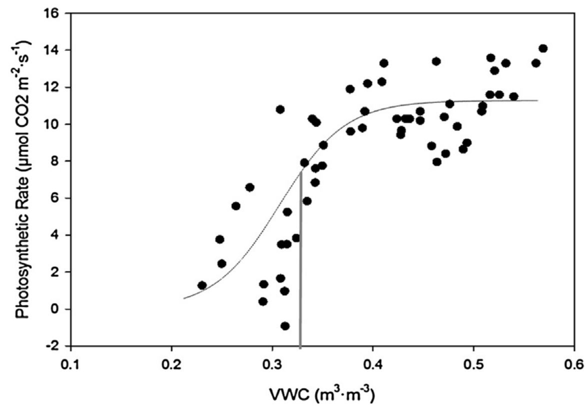

Fig. 1. The relationship between photosynthetic rate and volumetric water content of 'Alice' oakleaf hydrangea plants characterized by a 3 parameter sigmoidal curve photosynthesis = 11.2915/(1 + exp(−(x − 0.3072)/0.0326)), R^2 = 0.67. The irrigation threshold chosen at 90% maximum predicted photosynthetic rate is shown by the grey vertical line. *n* = 5.

The two irrigation systems tested in this experiment were on-demand (OD), a system with a physiological basis, and daily water use (DWU). Both programs calculated the difference between the instantaneous VWC and container capacity and applied the exact water volume required to return the substrate to 100% container capacity. For this research, the term container capacity represents the substrate moisture content following irrigation once gravitational water has drained but before evaporation losses occur. The main difference between the two systems was the static timing for initiation of irrigation in DWU versus dynamic irrigation scheduling for OD. In OD plots, irrigation was triggered instantaneously when the average sensor reading fell below 0.33 $m^3\ m^{-3}$ volumetric water content. This value was chosen based on a preliminary experiment that recorded repeated measurements of photosynthetic rate in plants as the substrate became drier (Hagen, 2013). A sigmoidal curve best described the relationship between photosynthetic rate and VWC. The selected irrigation set point, 0.33 $m^3\ m^{-3}$, corresponded to the substrate moisture level that supported photosynthesis at 90% of maximum predicted photosynthetic rates (Fig. 1), which corresponded to when 92% of plant available water had been used. Our hypothesis was that maintaining photosynthetic rate at 90% or greater of the maximum rate, growth would not be reduced but substantial water savings could be achieved. Triggering irrigation only when the substrate reached this set point allowed for flexibility in irrigation timing; plants were automatically watered as many times as necessary on high water use days (high evapotranspirational demand), and irrigation was withheld on days of low water use. DWU was irrigated on a static 24-h cycle. Daily water use during the previous 24-h cycle was calculated as the difference between 100% container capacity and the instantaneous VWC measured immediately prior to irrigation. The program multiplied the VWC difference by the container volume and divided by the irrigation flow rate to calculate irrigation time. Examples of irrigation scheduling for each program can be seen in Fig. 2. Container capacity was determined in preliminary experiments to be 0.53 $m^3\ m^{-3}$ for the Kentucky greenhouse study and 0.50 $m^3\ m^{-3}$ for all other studies (Hagen, 2013). For DWU, an afternoon irrigation