A Novel Automated System for Irrigation and Simulating Drought Stress in Potted Plants

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Significance to Industry: We have developed an automated watering system that has potential use in the irrigation of greenhouse and nursery crops and in studies related to drought stress. Using this system, plants can be grown based on plant water requirement by maintaining a target substrate moisture level optimal for a particular species. The system results in zero leaching and minimal wastage of irrigation water and at the same time completely automates irrigation. The watering system can maintain the volumetric water content of the substrate at any target level for prolonged periods, which could be very useful in drought stress research. We hope that this system can be used as a prototype for a future generation of automated irrigation controllers to achieve significant reductions in labor costs, irrigate plants based on plant water requirement, minimize runoff and water use, and impose precisely controlled drought stress in experiments.

Nature of Work: Overhead irrigation systems, like sprinkler-, boom-, and drip-irrigation, and subirrigation systems, like ebb-and-flow and flooded floor irrigation, can reduce labor costs compared to hand-watering, while subirrigation also prevents leaching. However, these irrigation systems do not irrigate the substrate based on the actual plant water requirement or with the minimum amount required for optimal plant growth. This is due to the fact that these systems can not wet the substrate to a target moisture level desirable for a particular species. Often times, these systems irrigate the substrate close to saturation, even if this is not optimal for crop production or to minimize leaching. An ideal automated irrigation system will turn on irrigation whenever plants require water and maintain a constant water supply for plants. Accurate and frequent measurements of substrate moisture status are the key components in developing irrigation systems based on plant water requirement. Such an irrigation system can maintain the substrate moisture content (θ) by frequent measurements of θ and adding small volumes of water to the substrate as needed to maintain a constant θ. An irrigation system based on plant water requirement will reduce labor costs for irrigation, wastage of irrigation water, nutrient leaching, and avoids excess or deficient irrigation. Such an irrigation system might also have important applications in physiological experiments. Currently, drought stress often is imposed by completely withholding water from the plants or by daily addition of only a fraction of the total water transpired by plants. Both these methods are not ideal for container-grown plants, as in the former method the rate at which drought stress develops after withholding water is not controlled and usually faster than under field conditions and the latter method can be time-consuming. Automatic maintenance of a particular θ would solve this problem and the target θ can be changed according to experimental needs. The objective of this research was to test the efficacy of a newly-developed automated watering system, which can maintain different levels of θ for irrigation purposes or simulating drought stress.

Four bedding plant species, *Impatiens walleriana* Hook. f, *Petunia hybrida* Vilm., *Salvia splendens* Sellow ex Roemer & J.A. Schultes and *Catharanthus roseus* (L.) G. Don (vinca) were grown from seed in 96-cell plug flats. One seedling from each species was transplanted into one of the four corners of a 17.5 L plastic container to ensure that all species were exposed to the same moisture level. A soilless substrate (Fafard 2P, Fafard, Anderson, SC) was used with approximately 22.5 g of a slow release fertilizer (Osmocote 14-14-14, Scotts Co., Marysville, OH) added to each container. Seedlings were irrigated amply (a $\theta > 0.4\ m^3 \cdot m^{-3}$) for a week after transplanting before subjecting them to θ treatments. Treatments comprised of four distinct θ moisture levels, with θ set points of 0.09, 0.15, 0.22, and 0.32 $m^3 \cdot m^{-3}$.

We built an irrigation system (Fig. 1) that uses ECH_2O moisture sensors (Decagon Devices, Pullman, WA) interfaced with a datalogger and solenoid valves connected to a relay controller. Frequent and precise measurements of the θ were accomplished using calibrated ECH2O dielectric soil moisture sensors (substrate specific, Nemali and van Iersel, 2004; $\log_{10} (\theta, m^3 \cdot m^{-3}) = -3.035 + 6.87 \times V - 4.305 \times V^2$, $R^2 = 0.91$). Substrate temperature was measured with thermocouples to automatically correct for temperature effects on the θ measurements. To control irrigation, solenoid valves were connected to a relay driver (SDM-CD16 AC/DC controller, Campbell Sci.). Each solenoid and port of the relay driver were related to one of the containers used in the study and irrigated the substrate in the respective containers. When the datalogger measured a lower θ than the target value in any container, it opened the solenoid valve that controlled irrigation of that container. The duration of each irrigation event was controlled by supplying power to the solenoid valve for a one minute, during which 100 mL was supplied. The volume of water supplied to the substrate during each irrigation was controlled using pressure compensated drip emitters (Rain-Bird irrigation, Tucson, AZ). The water was applied using 30 cm dribble rings with 7 holes (Dramm, Manitowoc, WI).

Measurements included daily average θ, number of irrigations in each treatment, total water-use by plants [number of irrigations × 100/1000) + $(\theta_{initial} - \theta_{final}) \times 15$, where 100 is the volume (mL) of water added by each irrigation, dividing by 1000 converts mL to L, $\theta_{initial}$ is θ before imposing treatments, θ_{final} is the final θ in the substrate, and 15 is the approximate volume (L) of the substrate in the containers], leaf transpiration rate (E), shoot dry mass, and transpirational water use [ratio of total crop water use and total shoot dry weight of all four species in any container]. The experimental design was a split plot design with two replications. An experimental unit consisted of one of the four plants in each container. Statistical analyses were performed using Proc GLM of statistical analysis software (SAS, SAS systems, Cary, NC). In the analyses, different species and moisture levels were treated as class variables. Means were separated using Tukey's HSD or Fisher's protected least significant difference (LSD) with a P-value < 0.05 considered to be statistically significant.

Results and Discussion: Except for a short period (1 to 2 days) after each irrigation, and particularly in drier treatments (0.09 and 0.15 $m^{3}\cdot m^{-3}$), the watering system maintained the θ at a constant level (Fig. 2). In the drier treatments the θ was 2-3% higher than the set point for one to two days after each irrigation. The mean θ maintained was 1-3% higher than the target value in each treatment, with deviations from the target level being more pronounced in the drier treatments. Mean shoot dry mass of all species was similar at a θ of 0.09 and 015 $m^{3}\cdot m^{-3}$. Mean shoot dry mass was higher at a θ of 0.22 $m^{3}\cdot m^{-3}$ compared to 0.09 and 0.15 $m^{3}\cdot m^{-3}$, and was not different between 0.32 and 0.22 $m^{3}\cdot m^{-3}$ (Fig. 3). Distinct levels of θ resulted in differences in the E and transpirational water use of plants. The effect of different θ on E of plants depended on the species (Fig. 4). In general, E was higher at higher θ. There were no differences in E of species at the two lowest moisture treatments. At a substrate moisture level of 0.22 $m^{3}\cdot m^{-3}$, E of vinca was higher than salvia and petunia, and was not different from impatiens. At the highest moisture level, E was not different among salvia, petunia, and vinca, however E of vinca was higher than impatiens. Transpirational water use was highest at the highest θ level, did not differ between 0.15 and 0.22 $m^{3}\cdot m^{-3}$, and was lowest in the driest treatment (Fig. 5).

The watering system was able to maintain θ for a long period within an acceptable range (2-3%) of the target value. Fluctuations in the θ seen in drier treatments can be minimized by using a shorter irrigation interval (as opposed to 1 minute used in this study). Based on these results, to maintain a particular average θ, the set point needs to be 2-3% lower than the desired θ. Unlike other irrigation systems, which often result in leaching losses and run-off (sprinkler and boom systems) or saturate the substrate (subirrigation), our system had zero wastage and resulted in normal growth of all species at a θ level of 0.22 $m^{3}\cdot m^{-3}$. The system irrigated plants 3-4 times daily in the two highest θ treatments with little maintenance. Regardless of the time of the day, the system irrigated the plants when the substrate moisture fell below the target level. The system also has a potential use in the field of drought stress research. Transpiration rate and transpirational water use of plants were significantly different among moisture treatments and species indicating that the system resulted in different physiological responses at different levels of θ. The system was able to precisely control different levels of drought stress imposed on plants.

Literature Cited:

1. Nemali, K.S., and van Iersel, M.W. 2004. Two new moisture sensors for horticultural substrates : ECH$_2$O and Theta probes. HortScience 39: 763.

Figure 1. Schematic diagram showing various parts of the watering system. 1. pressure regulated water source, 2. water line from source, 3. inlet tubing for solenoids, 4. solenoid valve, 5. outlet tubing, 6. drip emitter, 7. ECH20 sensor, 8. thermocouple, 9. drip line (ring), 10. CR10x datalogger, 11. AM25T multiplexer, 12. SDM-16AC/DC controller (relay driver). 13. power supply to solenoids, 14. datalogger power supply, 15. connecting wires between CR10x and AM25T, 16. connecting wires between CR10x and SDM-16AC/DC controller. Although this system can supply water to 16 containers, for clarity only one container is shown.

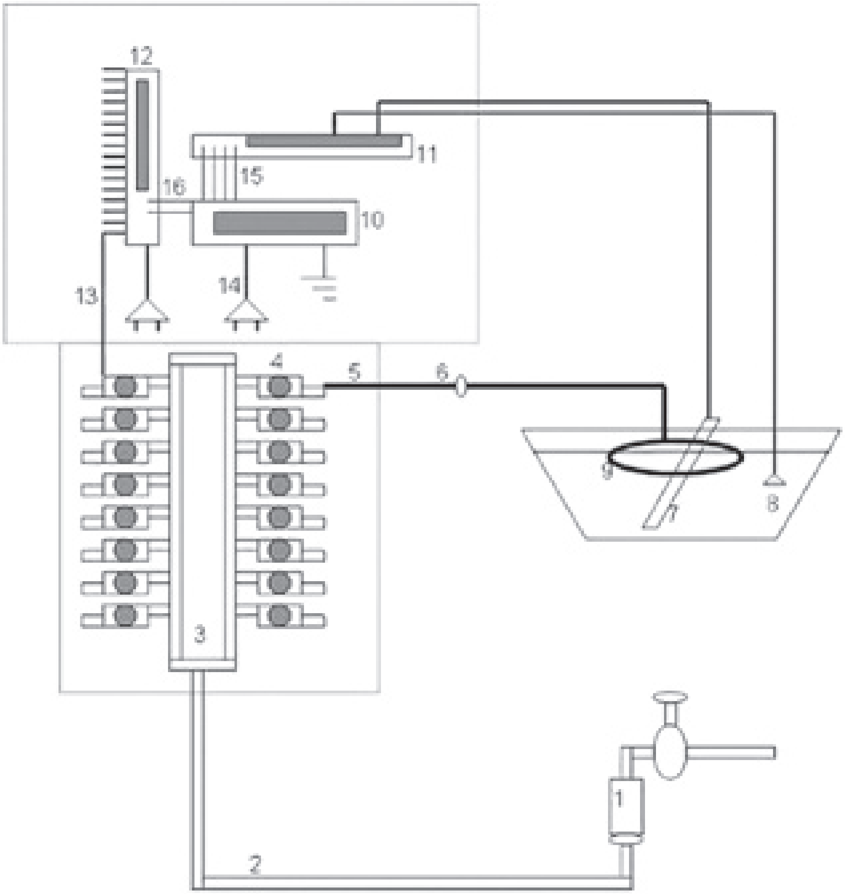

Figure 2. Daily average volumetric water content of the substrate (θ) maintained in different moisture treatments during the study. The dashed lines indicate the target θ at which the substrate was irrigated.

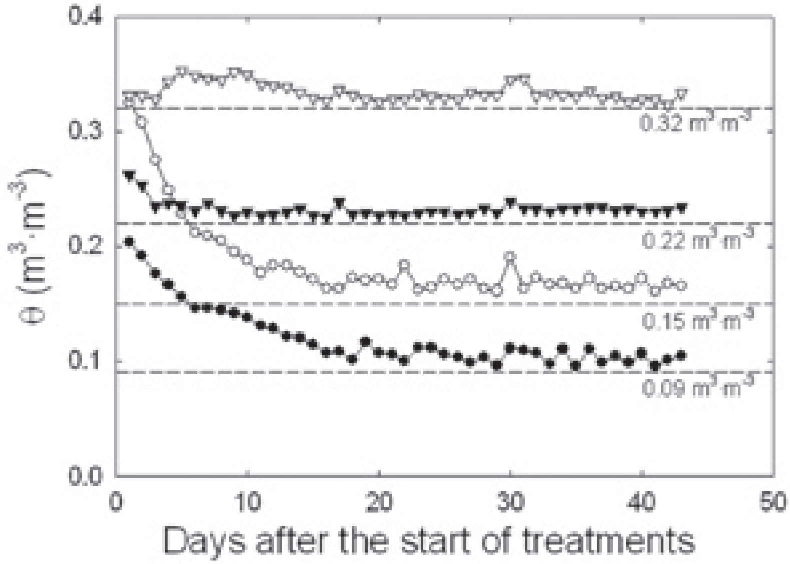

Figure 3. Mean (n = 8) shoot (leaf + stem) dry mass of all species at different substrate moisture levels (θ). Means were separated using Tukey's HSD. Means with the same letter are not significantly different. Error bars indicate standard error of the mean.

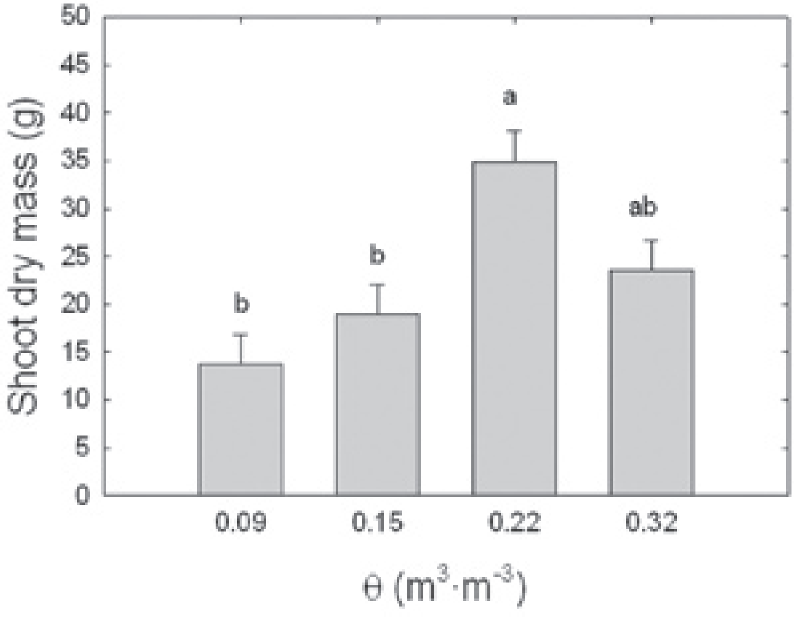

Figure 4. Mean (n = 2) transpiration rate (E) of vinca, salvia, impatiens, and petunia grown at different substrate moisture levels (θ). The error bar represents the least significant difference ($P < 0.05$) to compare means among different species within a moisture level or among different moisture levels within a species.

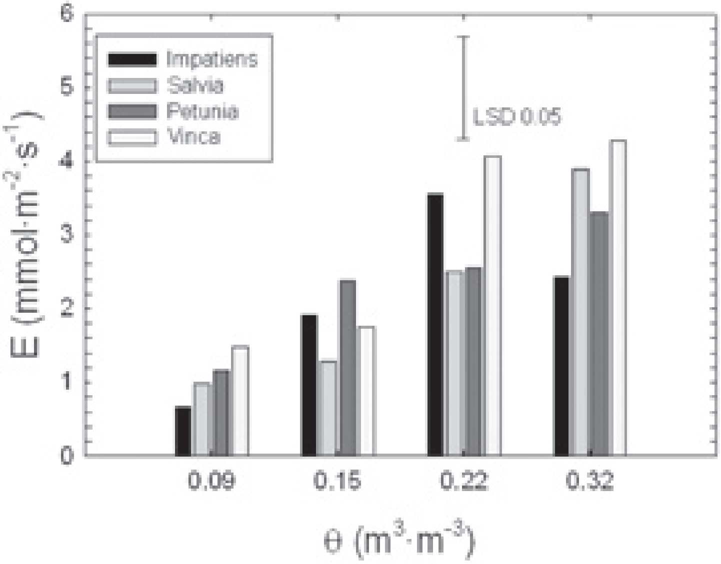

Figure 5. Transpiration water use (mL H_2O used per gram of plant dry matter) of plants in different moisture treatments. Error bars represent standard error of the mean (n = 2). Means with the same letter are not significantly different (Tukey's HSD).