From Forest Nursery Notes, Winter 2012

19. © Optimizing substrate moisture measurements in containerized nurseries.
Daniels, A. B., Barnard, D. M., Chapman, P. L., and Bauerle, W. L. HortScience 47(1):98-104. 2012 .

HortScience 47(1):98–104. 2012.

Optimizing Substrate Moisture Measurements in Containerized Nurseries

Alex B. Daniels and David M. Barnard
Department of Horticulture and Landscape Architecture, Colorado State University, 1173 Campus Delivery, Fort Collins, CO 80523-1173

Phillip L. Chapman
Department of Statistics, Colorado State University, Fort Collins, CO 80523-1877

William L. Bauerle[1]
Department of Horticulture and Landscape Architecture, Colorado State University, 1173 Campus Delivery, Fort Collins, CO 80523-1173

Additional index words. irrigation, pot-in-pot, sample size, sensor variability, tree production, volumetric water content

***Abstract*. The primary goal of this study was to determine the optimum number of substrate moisture sensors needed to accurately determine substrate water content for 10 tree species in a containerized nursery. We examined variation in volumetric water content (VWC, $m^3 \cdot m^{-3}$) within containers, within species, among species, and over time. Across time, differences among species were not significant (*P* = 0.14). However, differences among time periods and the interaction effect between species and time periods were significant (*P* < 0.001). Seasonal differences in within-species variation were also evident in nine of the 10 species. In an attempt to understand species-specific mechanistic factors that influence within-species variation in VWC, we accounted for physiological and morphological differences affecting transpiration with a spatially explicit mechanistic model, MAESTRA. Neither estimated transpiration rate per whole crown or m^2 of leaf area could explain variation in VWC. Based on our results, we recommend species-specific sensor deployment and report sensor quantities that estimate the mean substrate VWC of each species within a confidence interval of ± 5% VWC. Given the economic value of water and its control on biomass production, we conclude that nursery managers can maintain optimal substrate moisture with minimal sensor deployment.**

Substrate moisture is an important component of crop water status because it controls the partitioning of water and energy fluxes. In container-grown production systems, the volume of water that can be held in the rhizosphere is restricted, and effective irrigation is required to replace water lost through transpiration and surface evaporation. Quantifying the amount of water to be replaced requires accurate characterization of the availability of water within the container and the rate of plant water use (Vereecken et al., 2008). These values may differ within individual containers, from one container to the next, and among species within a nursery. A review of the literature reveals that there is a paucity of data to address the variability of substrate moisture among species grown in nursery containers. For example, Williams (1978) found substrate moisture to increase with container depth; however, it was undetermined if the relationship persisted or varied among species. Most importantly, previous studies fail to fully report the variation in substrate moisture among nursery containers of the same species, leaving the measurement sample size for adequate substrate moisture characterization within and among populations unknown. Consequently, there is a need to investigate substrate moisture variation among containers of the same species and among groups of different species in an intensively managed containerized nursery.

Over the past decade, relatively inexpensive substrate moisture sensors have become commercially available (e.g., Decagon Inc. Model EC-5; Irrometer Inc. Model Watermark 200SS). By logging the sensors with wireless nodes, substrate moisture data can be broadcast throughout a horticulture operation and transmitted to a base station linked to the World Wide Web (e.g., Rundel et al., 2009). Access to live substrate moisture data creates the potential to automate irrigation according to species-specific demand. A relatively straightforward approach involves defining a desirable range of substrate moisture, below which irrigation is initiated and above which irrigation ceases. A more mechanistic method could use substrate moisture data to validate species-specific transpiration model predictions, thus providing a real-time assessment of model performance. Regardless of the specific implementation, the ability to remotely monitor substrate moisture in real-time allows for better informed irrigation management decisions.

Although the technological advances are an important achievement, deploying substrate moisture sensors in container-grown plant material presents a unique challenge as compared with field placement. At the container scale, substrate moisture content is directly affected by the rate of root water uptake, which is primarily driven by the rate of leaf-level transpiration and the total transpiring leaf area. Furthermore, root density distribution, a variable that can be species-dependent, and substrate surface evaporation affect water extraction patterns (Andreu et al., 1997; Coelho and Or, 1998; Hupet and Vanclooster, 2005), potentially confounding the placement of substrate moisture-monitoring devices. A discontinuous medium (e.g., substrate within isolated containers) also prevents the use of spatial interpolation techniques and requires estimating substrate moisture from a population of individuals (the containers) rather than as a continuous function across a field. Given the relatively small volume of water accessible to plants in containers, these estimates must be precise to effectively maintain suitable substrate moisture levels. The precision of substrate moisture estimates can be improved with additional sensors, but an economically practical implementation requires a balance between cost concerns and sufficient sampling.

The objective of this study was to assess substrate moisture variation in container-grown plant material and determine an optimum sensor deployment accordingly. Specifically, we analyzed the variation in substrate moisture within individual containers, within blocks of trees of the same species, among groups of different species, and explored the change in within-species substrate moisture variation over time. We tested the hypothesis that the optimum number of substrate moisture sensors varies among species and changes with time. After establishing the amount of within-species variation in measured substrate moisture, we determined the number of substrate moisture sensors required to accurately estimate mean VWC ($m^3 \cdot m^{-3}$) for each study species within a 95% confidence interval no wider than ± 5% VWC. To investigate the contributions of species-specific morphological and physiological transpiration factors that might influence variation in substrate

Received for publication 5 Oct. 2011. Accepted for publication 21 Nov. 2011.
We thank Willoway Nursery and its staff for donating the trees, site, and assistance for this study. We also thank George Kantor, David Kohanbash, and their team at Carnegie Mellon University for their work on the wireless node network used in this study. We thank the following funding agencies for partial support of this study: U.S. Department of Agriculture–National Institute of Food and Agriculture, Specialty Crops Research Initiative Grant (Award No. 2009-51181-05768) and U.S. Department of Agriculture–Floriculture Nursery Research Initiative, Cooperative Agreement (Agreement No. 58-6618-2-0209). Decagon Devices Inc. subsidized equipment costs in Award No. 2009-51181-05768.
[1]To whom reprint requests should be addressed; e-mail bauerle@colostate.edu.