Time Domain Reflectometry Accurately Monitors Plant Water Use and Reduces Leaching Volumes in Soilless Substrates

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Nature of Work: Horticultural soilless substrates have large pore spaces and a small range of easily-available water (EAW) for optimum plant growth, compared to most natural soils (5). Easily-available water can be measured based on the matric potential (Y_m) of the substrate. Soilless substrates generally hold EAW in an Y_m range from 0 to -10 KPa, with the majority of free water available from 0 to -5 KPa (4,5,6). Water release curves follow a characteristic shape, yet vary according to the substrate composition and particle size (4). Container geometry also affects the water retention characteristics of a substrate, particularly container height (5). Gravity acts in the vertical plane, with increased drainage from taller containers of the same volume. A taller container therefore holds proportionally less water, as a percentage of water content by volume (i.e. decreased Wv). Accurate irrigation parameters should therefore be based on specific substrate characteristics and container height.

Water-release curve data can be used to define precise irrigation applications if an accurate method for measuring Wv is available. Up until now, no technology has existed to do this with any degree of precision in soilless substrates. Accurate monitoring and control of irrigation amounts will retain nutrients in the root zone (by increasing the residence time), and maximize plant growth, while minimizing leaching volumes. Time Domain Reflectometry (TDR) has been shown to accurately measure Wv in a range of soilless substrates, but few studies (2,1,3) provide information on the variability of such data. Also, there are few data to indicate how Wv and plant water use are correlated in soilless substrates, or if measurement of Wv can accurately sense plant water stress.

Materials and Methods: *<u>Experiment 1:</u>* Murray et al. (6, 7) described how a modified tension table was used to repeatedly measure the volumetric water content (Wv) and TDR output of six soilless substrates at three column heights, and how each substrate has a very narrow range of EAW in the range of 0 to -10 KPa. The six soilless substrates were selected based on their prevalence in the container nursery industry and/or their differences in particle type: Pro-Mix 'BX', a commercial pine-bark mix, a commercial hardwood-bark mix, medium-grade perlite, rockwool, and sieved washed sand (as a uniform particle size control). The heights of each substrate column were equivalent to commercial #1, #3, and #5 containers with heights of 6", 8" and 10" (15, 20 and 25cm), respectively.

Experiment 2: *Rhododendron azalea* cv. 'Hot Shot' liners were transplanted into 3-gallon, (8") containers and grown for one year in each of the six substrates (40 plants per substrate) in a greenhouse, under standard cultural conditions (7). Eight plants were randomly selected from each group and placed in a walk-in growth chamber in a randomized complete block design, with each block containing 4 replicate plants of each substrate (n=48). The growth chamber was fitted with metal halide and incandescent light bulbs that could be programmed to increase light intensity during the day, to simulate natural growth conditions; the temperature was maintained at a constant 75F (25C). The photoperiod consisted of an nine-hour dark period and 15 hours of light on the following schedule, ramping up and down every 3 hours from 300 (low), to 600 (moderate) and 1000 μmol/m^2/s, (high light) respectively (7). Plants were kept well watered for 3 days prior to (and re-watered to container capacity on) Day 1. TDR (and hence Wv) measurements were automatically logged on a continuous basis throughout the study period. Leaf stomatal conductance (g_s) of similarly aged leaves on each plant was measured mid-way through each incremental light period each day, using a LiCor 1600 Steady State Porometer. Measurements of Wv were carried out until wilt, 14 days later, whereas g_s measurements were taken until a sharp decline was apparent, due to the initiation of water stress (7).

Experiment 3: The objectives of this study were firstly, to determine whether sensor placement in relation irrigation method and emitter placement had an effect on sensor performance for five of the substrates, (i.e., whether substrate porosity and/or other effects interfered with the precision of sensor performance), and secondly, whether TDR irrigation could significantly reduce leaching volumes. The study was set up as a two by two factorial in a completely randomized design (7); factor one was sensor placement, in either the vertical or diagonal plane; the second factor was emitter type – spray stake vs. drip irrigation (Fig. 3). Forty plants per substrate (n= 10 per treatment) were used in this study. A Campbell TDR100 system with 7" (18 cm) sensors was used to monitor all 40 plants in each substrate, with a cycle time of approximately one sensor per second. This was an ideal monitoring interval to use with spray stakes due to their relatively large water output. Irrigation cycles were initiated at -10 KPa, and a -1 KPa set point was selected to terminate irrigation events. The moisture content of each of plant was measured every two hours for 7 days. Replicate leachate totals were collected every day and summed for the study period. Since some treatments had no leaching, this study required a nonparametric analysis. Proc NPAR1WAY (SAS, Institute) was used to analyze the data using a rank transformation procedure (7).

Results and Discussion: An example of the relationship between substrate Wv and TDR output is given for Pro-Mix (Figs. 1a , b). Relationships shown here are indicative of changes for all substrates studied in Exp. 1. Mean coefficients of variance for TDR measurements in all substrate and column heights ranged from 0.8% to 7.9% (7), proving that TDR can precisely measure water contents in soilless substrates under most conditions. Substrate water-holding capacity decreased sharply between 0 KPa and -10Kpa. Water-release and TDR curves for each substrate indicate that Wv is primarily determined by substrate characteristics. However, container height also affects Wv (Fig. 1b), especially at substrate Y_m near 0 KPa (container capacity). Thus, TDR sensors should be calibrated with Wv data based on container height (Fig. 1a), if irrigation scheduling set points are close to 0 KPa. Irrigation initiation at -10 KPa appears ideal from these results, but only if the species does not experience water stress at that substrate Wv.

Stomatal conductance (g_s) values during a drying cycle are shown for azalea grown in pro-mix substrate (Fig. 2). Azalea plants in the other substrates showed similar trends; no correlations were made between substrates (7). All plants showed a decline in g_s when the Y_m fell below -10KPa (Fig. 2). The Wv of the substrate showed a steady decline after the last irrigation on day 1, as expected (Fig. 2). Interestingly, a decline in g_s was evident nine days before wilt was observed, but 5 days after the last irrigation event. Both time periods were surprisingly long.

The TDR cyclic irrigation system precisely controlled irrigation events, with an initiation at -10KPa and a termination of irrigation at -1KPa matric potential. However, the placement study indicated that sensors need to be placed vertically in the wetting zone to minimize leaching volumes, especially when the wetting zone is restricted (as with drip emitters). If not, large leaching volumes occurred with most substrates (Table 1). It is apparent that sensor placement is less important with spray stakes, but diagonal placement may also be preferable, since great care was taken in this study to ensure even coverage of the surface with each spray stake in each pot.

Significance to Industry: These experiments provide the first comprehensive study of TDR technology in soilless substrates. Conceptually, the technique has shown to be very precise and it can be adapted to accurately monitor and control irrigation schedules in horticultural situations. Further development of cheap wireless probes would enhance the adoption of this technology by the industry in the future.

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Table 1: The effect of combination of emitter and sensor placement on mean leaching volume (± standard error) in ml/plant /irrigation event. Significance of placement effects (vertical vs. diagonal) indicated by P-value.

Substrate	Drip Vertical (ml)	Drip Diagonal (ml)	Significance (P-value)	Spray Vertical (ml)	Spray Diagonal (ml)	Significance (P-Value)
Pro-Mix	33(± 13)	276(± 38)	P< 0.001	0(± 0)	27(± 27)	P = 0.22
Hardwood Mix	0 (± 0)	37 (± 9)	P < 0.001	1 (± 1)	12 (± 8)	P = 0.15
Pine Bark Mix	0 (± 0)	623(± 42)	P < 0.001	14(± 8)	32 (± 9)	P = 0.33
Perlite	0 (± 0)	168(± 30)	P < 0.001	0(± 0)	6 (± 4)	P = 0.21
Sand	8 (± 4)	57 (± 15)	P < 0.03	70(± 27)	9 (± 5)	P = 0.09

Fig. 1. Standard (a) Time Domain Reflectometry (TDR) and (b) Volumetric Water Content (Wv) curves for Pro-Mix 'BX' soilless substrate in #1, #3, #5 containers, with heights of 15, 20, and 25-cm respectively. Error bars represent the standard error about the mean (n=6).

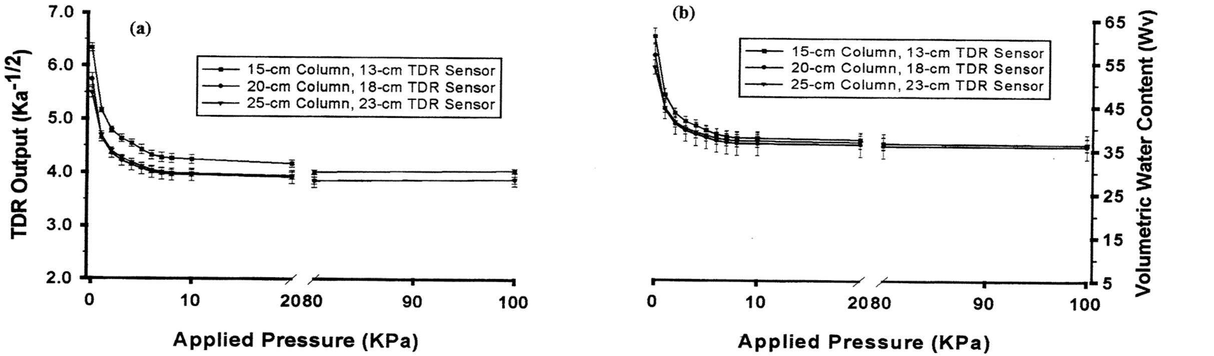

Fig. 2. Mean stomatal conductance of Azalea plants in 'Pro-Mix' substrate at high (1000), mid (600), and low (300 umol/m²/s) light levels, on successive days after irrigation to container capacity (day one). Arrows indicate the day at which soil matric potential measurements were 0 KPa and -10 KPa.

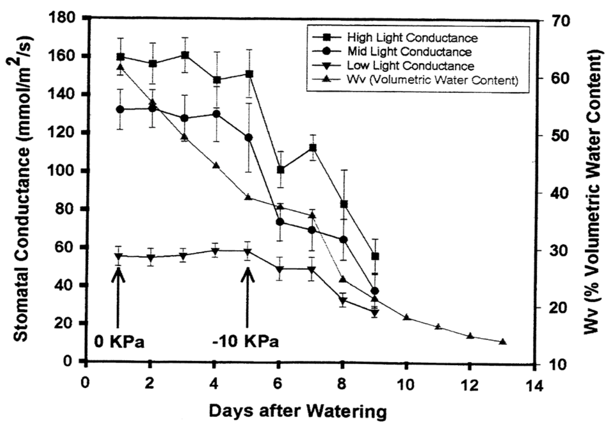

Fig. 3. Diagram showing a drip or spray stake, diagrammatically represented by the blue line at the left of the plant stem. The placement at left represents vertical sensor placement in the plane of the emitter (Drip-Vertical or Spray-Vertical). At right is the diagonal placement (Drip-Diagonal or Spray-Diagonal)