Water Management

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Leachate Volumes and Irrigation Efficiency of Various Cyclic Watering Regimes on 7-gallon Pot-In-Pot 'Constellation' Dogwood.

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Index Words: leachate, irrigation, cyclic watering, pot-in-pot, dogwood

Nature of Work: Bare root 'Constellation' hybrid dogwood liners were planted and grown in a #7 pot-in-pot production system under three irrigation regimes (1X, 1.5X, 2X). Initially the 1X regime was 2 cycles of 5 minutes each for a total "on" time of 10 minutes. The 1.5X regime was provided by two separate treatments, 3 cycles daily of 5 minutes per cycle for a total "on" time of 15 minutes, or 5 cycles per day of 3 minutes per cycle for a total "on" time of 15 minutes. Later, when irrigation volumes were decreased, it became necessary to change to a 6 cycle regime in order to keep total irrigation volumes the same for both 1.5X treatments. The 2X regime was 4 cyles of 5 minutes each for a total "on" time of 20 minutes. Three levels of Osmocote fertilization was superimposed on this design in a factorial arrangement of treatments, with irrigation being the main plot, fertilizer level randomized with each main plot, with four replications and two plants per experimental unit.

As evaporation and transpiration demands decreased in late summer and autumn (Figure 1), the amount of water applied was decreased proportionately in each regime to achieve less leaching and better irrigation efficiency. At four different dates (6 Aug, 21 Oct, 27 Oct, 4 Nov) we collected the output of each emitter for the first cycle of the day and recorded ml volume. We poured this evenly onto the surface of the container, caught the leachate in a tub and measured its volume. A 100 ml sample was collected to determiner EC and pH. Daily volumes for applied, used, and leached were obtained by multiplication (vol x # cycles) rather than collection of each cycle and percent irrigation calculated as ml water used per day per container divided by ml water applied daily times 100. The controller was set to allow an "off" time of two hours between cycles, and started cycling through the various solenoid stations before dawn at 15 minute intervals.

Results and Discussion: Analysis of variance showed no differences in height and caliper due to fertilizer treatments or to irrigation treatment. Mean height in Nov 99 ranged from 179 to 201cm (5.9-6.6 ft) for the 12 treatment combinations, while caliper was 24.4 - 26mm (approx. 1"). Table 1 shows that irrigation efficiency during the period of heaviest water application (up to 6 Aug) ranged from 75% to 60%. The more water applied, the more was used but also more was leached/day in terms of absolute volume. As the volume applied decreased, efficiency appeared to decline. This was probably in response to shorter days and cooler temperatures resulting in less evapo-transpiration. Visual observation showed plants were never stressed or wilted even during sunny fall afternoons. There was a 4-9% difference in irrigation efficiency of the 3 cycle treatment versus the 5-6 cycle treatment in the 1.5X regime, though the amount applied was virtually identical. The 5-6 cycle treatment became more efficient than the 3 cycle treatment as the volume applied was reduced as the season progressed.

Though we calculated daily volumes, the data was representative of conditions in the container immediately after the first watering cycle early in the day. While that cycle replenishes container capacity after the long overnight “off” period, it does not take into account the heavy plant transpiration demands that occur in early to mid-afternoon (4). Next year we plan to collect data for each and every cycle of each watering regime to document what effect the time of day has on percent irrigation efficiency.

Analysis of variance showed no effect of irrigation regime on mmhos EC on the various sampling dates. Differences in mean EC betwen fertilizer levels were noted as expected, and when irrigation volumes were reduced, EC increased slightly (Table 2). However, EC levels were low in August, indicating most fertilizer salts had been leached with excess irrigation.

Significance to Industry: This data supports previous research which indicates that growers can achieve efficient water usage and reduce leaching with a number of different cyclic watering regimes (1,2,3,4). Controllers should initially be set to apply between 3000 and 4000 ml water per day to a #7 pot-in-pot container, distributed over 2 or more watering cycles separated by at least 2 hours “off” time. Systems should be fine tuned to achieve high irrigation efficiency within a few weeks, by actual collection of applied and leached volumes on a representative sample of containers, to achieve 80% or better irrigation efficiency and minimize leachate losses of water and fertilizer.

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Table 1. Mean ml water applied daily per #7 'Constellation' dogwood, mean ml used, mean ml leached, and % irrigation efficiency of various cyclic watering regimes.

Period:	up to 6Aug99	7Aug 99-21Oct99	22Oct99-27Oct99	28Oct99-4Nov99
cycle duration:	5 min	3 min	2 min	1.5 min
2 cycles/day (1X)				
ml applied/day	4092	2465	1643	1386
ml used/day	3063	1150	848	778
ml leached/day	1029	1315	795	608
% efficiency[x]	75%	47%	52%	56%
3 cycles/day (1.5X)				
ml applied/day	6242	3770	2514	1886
ml used/day	4362	2125	1574	1157
ml leached/day	1880	1645	940	729
% efficiency	70%	57%	63%	61%
4 cycles/day (2X)				
ml applied/day	8289	4970	3312	2484
ml used/day	4953	2595	1532	1053
ml leached/day	3336	2375	1780	1431
% efficiency	60%	52%	47%	42%
5-6 cycles/day(1.5X)	5x3min	5x2min	6x1min	6x0.75min
ml applied/day	6243	4050	2431	1823
ml used/day	4073	2675	1631	1199
ml leached/day	2170	1375	800	624
% efficiency	65%	66%	67%	66%

* % irrigation efficiency = ml used/ml applied x 100.

Table 2. Mmhos EC of leachate from #7 containers of "Constellation" pot-in-pot dogwoods at four dates as irrigation volumes were reduced.

date	Osmocote level		
	1X	2X	3X
6 Aug 99	222 g[x]	228 fg	249 e
8 Oct 99	253 e	307 d	373 b
22 Oct 99	254 e	329 c	408 a
4 Nov 99	244 ef	315 cd	381 b

[x] Means followed by the same letter are not significantly different at the 0.05 level.

Constructed Wetlands Removal of Herbicides and Nutrients from Container Nursery Runoff

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Index Words: Constructed Wetlands, Container Nursery, Water Treatment, Pennant (Metolachlor), Princep (Simazine), Bulrush

Nature of Work: A field study was conducted in spring and summer of 1998 and 1999 at the Baxter, Tennessee wastewater treatment plant, where constructed wetland cells have been studied since 1992 (Kemp and George, 1997). A 5000 ft^2 container nursery was built on site with overhead irrigation. Water runoff from the container nursery was pumped into fourteen gravel subsurface flow constructed wetland cells. Bulrush, Scirpus validus was grown in seven of the 16 x 4 foot cells, and seven cells had no plants. The wetland cells were either 30 or 45 cm in depth. Three loading rates of runoff water containing herbicides and nutrients were added, corresponding to hydraulic retention times of two to twenty-one days. The removal of herbicides, Princep (simazine) and Pennant (metolachlor), and nutrients, nitrogen and phosphorus, in each of the constructed wetland cells was calculated and correlated with bulrush vegetation, loading rates, depth of cell and hydraulic retention time. Objectives of this study were to: (1) determine removal of Pennant (Metolachlor), Princep (Simazine), nitrogen and phosphorus from container nursery runoff in constructed wetland cells; (2) determine the effect of bulrush vegetation, flow, depth and aspect of constructed wetlands on herbicide and nutrient removal and; (3) design and install a pilot scale subsurface flow gravel constructed wetlands at a container nursery grower's site for removal of herbicides and nutrients and for demonstration to growers and other interested parties.

Results and Discussion: Constructed wetland cells with plants removed significantly more Princep (simazine), nitrogen and phosphorus than cells without plants. Cells with plants removed more Pennant (metolachlor) at two to eight day retention times, but at longer water retention times there was no difference between cells with plants and without plants. There was no difference with depth as to herbicide or phosphorus removal. Nitrogen removal was greater with cells 45 cm deep (89%) compared to cells 30 cm deep (76%). Removal of Princep (simazine) ranged from 57 to 96%, and Pennant (metolachlor) removal ranged from 18 to 95% of that applied. There was no significant difference in removal comparing the first year to the second year. In constructed wetland cells with plants, approximately 60 to 65% of herbicides were removed at the high loading rate, which was equivalent to a two or three day hydraulic retention time (Figures 1 and 2). Increasing the retention time to eight or more days improved removals to above 80% for cells with plants. Nitrogen removal was greater than 90% for all vegetated cells. Phosphate removal was greater than 85% for all vegetated cells except cell A, which had the shortest retention time.

Significance to Industry: A major limitation of utilization of constructed wetlands is the relatively large area of land required for adequate removal efficiencies. A goal would be to shorten the time required for water to be retained in the wetland and still achieve desired removals. A pilot subsurface flow gravel constructed wetland has been installed at a nursery in Smithville, TN, for evaluation. A demonstration of this wetland is planned for the Fall of 2000.

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Table 1. Princep (Simazine) % Removal Statistics

Variable	P value	Mean	Tukey Grouping
Vegetation	0.0001		
With		80.9	A
Without		60.3	B
Flow	0.0006		
240 (L/d)		57.9	A
120 (L/d)		66.5	A
60 (L/d)		85.0	B
Depth	0.5624		
30 cm		68.2	A
45 cm		73.1	A
Aspect	0.1533		
4:1		70.0	A
1:2		74.7	A

Figure 1. Average Princep (Simazine) Removal in Paired Wetland Cells

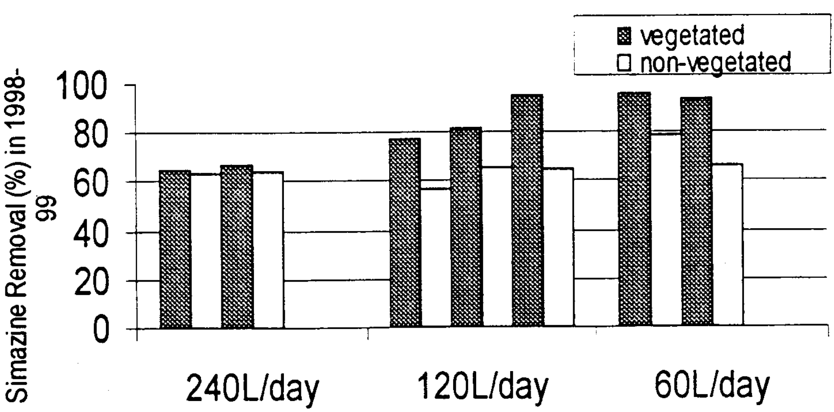
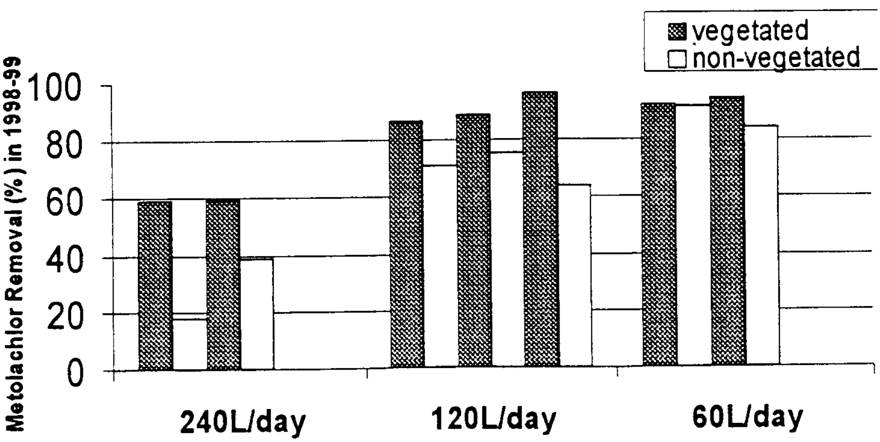


Table 2. Pennant (Metolachlor) % Removal Statistics

Variable	P value	Mean	Tukey Grouping
Vegetation	0.0010		
With		84.0	A
Without		68.4	B
Flow	0.0001		
240 (L/d)		50.5	A
120 (L/d)		82.4	B
60 (L/d)		92.7	B
Depth	0.3513		
30 cm		74.0	A
45 cm		78.5	A
Aspect	0.4425		
4:1		74.6	A
1:2		86.3	A

Figure 2. Average Pennant (Metolachlor) Removal in Paired Wetland Cells



Toxicity, Uptake, and Distribution of Metalaxyl and Simazine in *Typha latifolia*

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Index Words: Cattail, Pesticide, Remediation

Nature of Work: This research established toxicity thresholds to simazine (Princep) and characterized the uptake and distribution of simazine and metalaxyl (Ridomil, Subdue) by the emergent wetland plant, *Typha latifolia* (Cattail). This information is needed to determine the potential for use of this species within a plant-based system for removing pesticides from water.

Materials and Methods: *Toxicity.* Metalaxyl toxicity was not evaluated since other studies indicated that it was relatively non-toxic to plants. Simazine tolerance levels were determined by exposing plants to a series of six simazine concentrations (0-3 mg/L) in aqueous 10% Hoagland's nutrient media for 7 d. Toxicity tests were conducted in the lab at 25 ± 2°C under metal halide lamps with a photon flux density of 375 ± 25 µmol $m^{-2}s^{-1}$ and a 16 h light: 8 h dark photoperiod. Individual plants were exposed in glass jars to 250 mL of each pesticide concentration for 7 d. Plant roots were rinsed with distilled water after the 7 d exposure period. Plants were then placed in "clean" nutrient media and allowed to grow for an additional 7 d in order to observe any latent effects or recovery. Fresh weights were recorded before exposures, after 7-d exposure, and after the 7 d post-exposure period. These measurements were used to calculate the fresh weight gains during the 7-d exposure and post-exposure periods. This study used a completely randomized statistical design with 4 replications for each exposure concentration. Fresh-weight gain data were ranked and analyzed by ANOVA ($P = 0.05$). Results were further analyzed using calculated Least Significant Differences (LSD).

Uptake and Distribution. Metalaxyl and Simazine uptake and distribution were determined by growing plants in nutrient media amended with [^{14}C]-ring-labeled metalaxyl (0.909 mg/L) or simazine (0.242 mg/L). Reference plants were grown in un-amended nutrient media. Plants (reference and exposed) were randomly selected for analysis following 1, 3, 5, and 7 d growth in the radio-label-spiked nutrient media. Plants were dissected, freeze-dried, combusted, and analyzed by liquid scintillation spectroscopy. These studies were conducted in environmentally-controlled growth chambers (light intensity, 375 ±25 µmol $m^{-2}s^{-1}$generated by fluorescent and incandescent lamps; photoperiod: 16 h light: 8 h dark; relative humidity: 60%; and temperatures: 25°C light: 22°C dark). Water transpired through the plants was replenished with distilled, deionized water. Water use was recorded daily. In addition to harvesting the plant tissue, samples of the exposure solutions were analyzed for total [^{14}C] content by liquid scintillation spectroscopy.

Results and Discussion: *Toxicity*. Plants exposed to simazine displayed a dose-dependent reduction in fresh weight gains after the 7 d exposure and 7 d post-exposure periods (Figure 1). Cattail fresh weight production was reduced 84 and 117% at 1.0 and 3.0 mg/L simazine, respectively, after 7 d exposure. Fresh weight gains for plants exposed to 0.01, 0.03, 0.1, and 0.3 mg/L were statistically similar to those of the controls. No latent effects were observed for plants exposed to 0.01, 0.03, 0.1, and 0.3 mg/L after the 7 d post-exposure period. Chlorosis of affected plants was visible after approximately 5 d exposure. Leaf necrosis and desiccation progressed inward from the tips of the leaves.

Uptake and Distribution. All reported data were corrected for background activity by subtracting reference activity from activity in exposed plants. [^{14}C]metalaxyl and [^{14}C]simazine activity in the exposure solutions decreased with time (Figures 2 and 3). For metalaxyl, these reductions were 9, 17, 29, and 34%, respectively, after 1, 3, 5, and 7 d exposure. Reductions in simazine were 11, 21, 46, and 65%, respectively, after 1, 3, 5, and 7 d of exposure. Regression analysis indicated that the amount of activity remaining in the exposure solutions was inversely proportional to cumulative water-use by the plants (Table 1). Nearly all of the [^{14}C]metalaxyl and [^{14}C]simazine removed from the exposure solution was detected in the plants. For metalaxyl, 6, 13, 26, and 32% of the total activity added was detected in the whole plants after 1, 3, 5, and 7 d exposure, respectively. For simazine, 8, 26, 47, and 63% of the total activity added was detected in the whole plants after 1, 3, 5, and 7 d exposure, respectively. The mass balance for [^{14}C] was good throughout the tests, with unmeasured label never exceeding 5%. Some of the activity not accounted for throughout the experimental period may have been lost when plant roots were rinsed under the tap. Rinse water was not analyzed for activity. The accumulation of [^{14}C] in the plants was directly proportional to cumulative water-use by the plants. Analysis of the dissected plant tissues revealed significant accumulations of [^{14}C] primarily in the leaves (Figures 2 and 3). Minimal amounts of activity were detected in the roots and rhizomes, indicating that they primarily serve as pathways for acropetal transport.

Significance to Industry: Surface waters may be contaminated with pesticides by runoff, inappropriate application practices, or improper disposal of application equipment rinse water. These results indicate that the common cattail may be useful for removing pesticides such as metalaxyl and simazine from contaminated water.

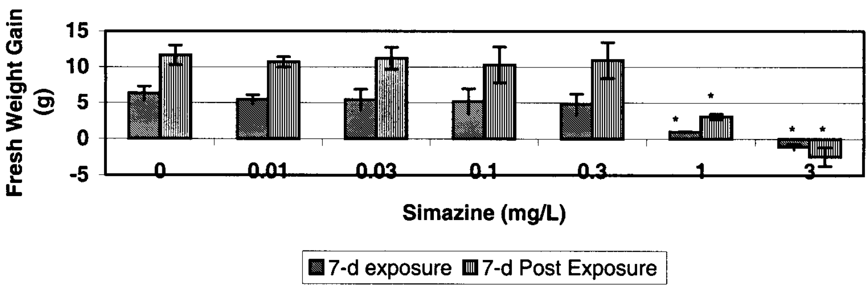

Figure 1. Toxicity of Simazine to *Typha latifolia*. *significantly different from control at P=0.05.

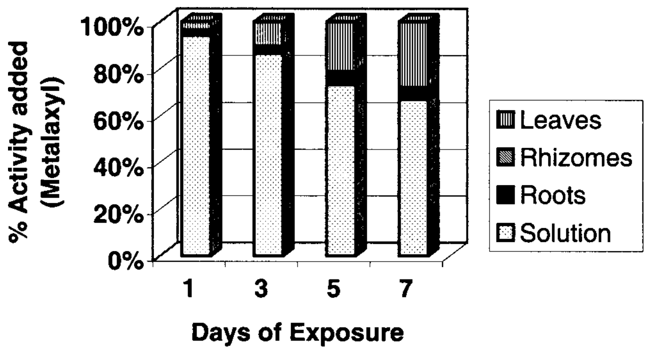

Figure 2. [^{14}C]metalaxyl dissipation from solution and uptake by- and distribution within- *Typha latifolia*.

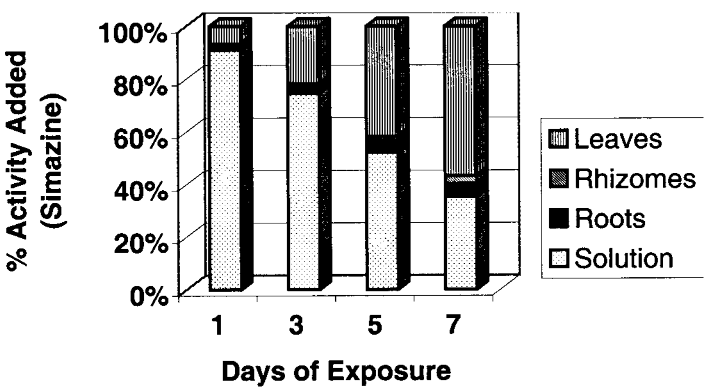

Figure 3. [^{14}C]simazine dissipation from solution and uptake by- and distribution within- *Typha latifolia*.

Table 1. Regression equations relating cumulative water use to metalaxyl and simazine dissipation from solution and accumulation in *Typha latifolia*.

% Remaining in Solution Relative to Cumulative Water Use
Metalaxyl: % remaining = -0.0008*(cumulative water used, mL) + 0.9286; $R^2 = 0.92$; $P = 6.28x10^{-07}$
Simazine: % remaining = -0.00156*(cumulative water used, mL) + 0.9562; $R^2 = 0.98$; $P = 1.35x10^{-09}$
% Accumulated in Whole Plants Relative to Cumulative Water Use
Metalaxyl: % accumulated = 0.0009*(cumulative water used, mL) + 0.0342; $R^2 = 0.95$; $P = 8.91x10^{-08}$
Simazine: % accumulated = 0.0015*(cumulative water used, mL) + 0.0598; $R^2 = 0.97$; $P = 4.12x10^{-09}$

Generating Water Release Curves with Simultaneous Time Domain Reflectometry Calibration in Soilless Container Media

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Index Words: Soilless Substrates, Water Release Curves, Time Domain Reflectometry, Available Water

Nature of Work: Horticultural substrates have large pore spaces compared to many soils, low water holding capacity, and a low range of easily available water for optimum plant growth. Water that is easily available to plants can be generalized based on matric potential (tension, suction pressure) of the substrate. Horticultural media generally have water easily available in the range from 0 to -10 KPa (KPa = 10^{-3} MPa), with the major volume of water available in the free pore space up to a tension of –5 KPa . Water release curves follow a characteristic shape, yet are offset based on adsorptive qualities of the particles in the media. For example, sand will absorb no water within the particle, holding water only in pore spaces and on particle surfaces, and will be essentially dry at matric potentials approaching –10 KPa. Peat moss and pine bark on the other hand, will absorb water within the particle and on charged surfaces, making a fixed percentage of total moisture content unavailable for plant uptake. Peat moss in general exhibits characteristics of unavailable bound and hygroscopic water near 30% volumetric water content.

Water release curve data can be used to improve the precision of irrigation applications, if a method for accurately predicting water content in soilless substrates is available. This can benefit producers by maximizing plant growth in optimal moisture ranges, while minimizing leaching volumes. Time Domain Reflectometry (TDR), a promising technique, can be used to monitor moisture in containers, quantifying volumetric water content based on the apparent dielectric constant of the substrate . TDR sensors can be manufactured to match container height, and calibrated to specific substrates. TDR can be used to schedule cyclic irrigation based on the average water content measured over the height of the container; this improves irrigation precision, maintains optimum plant growth, and minimizes leaching due to excessive irrigation volume .

Materials and Methods: Four soilless substrates were selected (Premier Pro-Mix ‘BX’, a commercial Pine Bark Mix, Perlite, and Quikrete Sieved Washed Sand as uniform control) on the basis of their prevalence in the container nursery industry and/or their differences in particle type. Particle size analysis was conducted at the North Carolina horticultural substrates laboratory (Table 1). Desorption curves were generated for each substrate with simultaneous TDR calibration using a modified tension table and positive applied pressure (= suction pressure). Ten independent replicate columns were desorbed for each substrate. Columns were 19.5 cm tall x 12.6 cm diameter (packed uniformly to the top) to represent the height of a substrate column in a #3 production (3 gallon) container. Each sealed column had a TDR sensor fixed in the top lid, with three 18 cm wave-guides positioned centrally vertical down the column. All columns were slowly wetted from the bottom to gradually force all air out of the substrates and to allow particle adsorption of water, and establish equilibrium. Upon saturation with known volumes of water, columns were allowed to drain freely by gravity (0 KPa), until leaching finished, determining container capacity. Positive pressure was then applied step-wise in increments of 1 KPa (0 - 10 KPa) and thereafter in 10 KPa increments to 60 KPa. Allowing forced leaching to finish and equilibrium to be established, the volume of water leached at each incremental pressure was measured for each replicate (n = 10), and the TDR output for each column measured. This quantified moisture content and sensor accuracy in the range of easily available water . TDR measurements were taken using a Tektronix 1502C metallic cable tester connected to a multiplexed Campbell Scientific data logger (Logan, UT). Upon completion of desorption, column substrates were weighed wet and re-weighed dry to verify absolute moisture content. The mean moisture content and TDR output (1/Vp = 1/Velocity of Propagation) at the various matric potentials are shown graphically with standard errors.

Results and Discussion: All water release curves were nearly asymptotic beyond a -10 KPa matric potential. This implies a limited range of easily available water in horticultural substrates for optimum plant growth. Pro-mix, pine bark mix, perlite, and sand were nearly asymptotic at respective water contents of approximately 36%, 24%, 27%, and 10%. This range of moisture content (suction beyond -10 KPa) represents hygroscopic and adsorbed water, which is unavailable for optimal plant growth. Horticultural substrates have easily available water up to –10 KPa; this is the range with significant volumes of water free in the large pore spaces. Soils, in contrast, have more water available in small and medium pore spaces, and is available across a broader range of pressure potentials. Therefore, irrigation scheduling should attempt to maintain moisture content at pressure between 0 and –10 KPa for optimal plant growth. Volumetric water content will vary at these pressures based on container height and substrate characteristics such as particle size distribution and particle type.

In all substrates, TDR output followed the curve of available water. TDR standard errors at each pressure potential were less than 2% of their respective mean, and generally less than the standard error associated with the volumetric moisture content at that pressure. TDR output CV's for all pressure potentials were averaged for each substrate as an overall assesment of variability: Pro-mix=3.94, pine bark mix=3.98, perlite=4.72, sand=2.65. Thus TDR appears to have a high degree of precision for measuring water content in a diverse range of horticultural substrates.

Significance to Industry: These results provide data to substantiate the range of easily available water in soilless substrates for optimum plant growth. Substrate curves are of similar shape, determined by matric potential of the substrate, and differ based on adsorptive qualities and pore space of each substrate affecting volumetric water content. Water release curves can be used in conjunction with TDR sensors to improve cyclic irrigation application precision (automated initiation and termination) that minimize leaching fractions, yet maintain optimal plant growth rates.

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Table 1: Particle Size Distribution (% weight)

Substrate	(>6.3mm)	(6.3mm to 2.0mm)	(2.0mm to 0.5mm)	(<0.5mm)	Bulk Density
Pro-Mix 'BX'	2.4	63.9	21.5	12.2	0.11
Pine Bark Mix	3.3	35.1	35.2	26.4	0.33
Perlite	0.0	55.2	26.4	18.3	0.13
Quikrete Sand	0.0	0.4	10.7	88.9	1.38