When to Fertigate: The Influence of Substrate Moisture Content on Nutrient Retention in Containerized Crop Production

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Significance to Industry: The agriculture industry, including nursery and greenhouse, is already absorbing rising fertilizer costs, averaging 9% in the decade from 2000-2010, fueled by pressures on fossil fuel and phosphorous markets (1). Given these challenges, the efficient fertilization of crops is, and will increasingly become, essential to the profitability and sustainability of the industry. In an overview of water management practices, Bilderback (2) reported that container leachate volume correlates positively with irrigation volume. Thus, water application efficiency directly relates to the use efficiency of mineral nutrients. Research herein investigates delivery efficiency of mineral nutrients via fertigation when initial substrate moisture content varies from dry (i.e. moisture content when conventional irrigation takes place) to wet (i.e. requiring no irrigation). Efficiency was measured using effluent electrical conductivity (EC) as a proxy for mineral nutrient leaching. Results indicate fertigation efficiency (decreased nutrient leaching) of *Ilex crenata* curvilinearly increased as pine-bark substrate moisture content increased from 38%, 44%, 50%, and 56% (gravimetrically). This was in part because observable leaching occurred much sooner (approx. 30 sec.) with lower substrate moisture content treatments. The authors hypothesize mineral retention is aided by a more uniform distribution of water (and mineral nutrients) as the result of increasing hydrating efficiencies at higher initial moisture content. This is believed to be a result of decreased preferential flow (i.e. channeling) at increasing moisture content (3); whereas, solute (water and mineral nutrient) retention and distribution in the container was greater when fertigating pots pre-hydrated (4). In conclusion, a fertigation event should not replace a scheduled irrigation event. Knowing that when crops require irrigation, mineral nutrients applied via fertigation will rapidly leach from containers, wasting resources and subsequent dollars.

Nature of Work: Globally, the pressures on the agriculture industry are increasing, and showing little sign of easing. The UN projects an increase in world population to approximately 9.6 billion by 2050 (5), putting pressure on agricultural producers, allied suppliers and associated resources. In the future, agriculture will also have to face the challenge of a projected increase in global resource demands, fueled by socioeconomic and demographic factors resulting from an additional 2.4 billion people (2013 ≈ 7.2 billion) (5). Given these massive challenges, the containerized nursery industry cannot be immune from these global trends. Nursery crop cash receipts alone were approximately $3.8 billion, of which 66% was a result of containerized crops, in 2007

(6). Timely and successful production of containerized crops relies on a balanced approach to water and nutrient management, which are in part a function of the soilless substrate utilized during production. Substrates differ widely in their physical and chemical constitution. Therefore, the choice of components and resulting substrates are key to successful containerized crop production. Understanding how a substrate interacts with water and nutrients will allow growers to optimize resource efficiency by implementing varying strategies dependent upon the substrate properties.

Wettability is considered to be an important factor in soilless substrate culture. Research in the 1960's by Letey et al. (7) described wettability as how easily a liquid can spread over the surface of a soil or substrate particle. The authors consider wettability to be a primary property influencing water distribution (and nutrient) within a soilless substrate. Plaut et al. (8) reported wettability of soilless substrate influenced hybrid tea rose growth by improving water-holding capacity. Bilderback et al. (2) demonstrated soilless substrates have lower water holding capacity than soil, requiring less water to be applied more frequently to minimize crop water stress. In a practical sense, research indicates that container leachate volume and total mineral nutrient loss will increase as irrigation application rate or total volume exceeds retention capacity of the substrate. Mineral nutrient loss is also a function of the type of fertilizer applied (4).

Fare et al. (9) demonstrated that three spaced irrigation events (i.e. cyclic irrigation) compared to a single irrigation event, both of which apply a total of 0.5 inch (13 mm) of water, reduced container leachate volume by 34%. More recent research by Fare et al. (10) found leachate volume could be further reduced by 54% and subsequent nitrogen leached reduced by approximately 47% when using a 30 minute to two hour resting phase form of cyclic irrigation, as opposed to continuous irrigation, both of which exhibited similar growth index and root distribution. Results by Fare and her colleagues support earlier research findings and imply that leaching is more prevalent in drier substrates and water application should not exceed substrate capacity.

Research to date has primarily focused on irrigation scheduling or water application quantity. Recently, Hoskins (4), investigating water and solute transport during irrigation events, suggests pre-irrigation container moisture content has an effect on preferential flow. Moreover, solute retention and distribution in the substrate was greater when fertigating pre-hydrated containers. This research builds on these findings and the work of others to suggest producers should consider pre-fertigation substrate moisture content as a means to increase resource retention efficiencies. Research herein investigates delivery efficiency of mineral nutrients via fertigation when initial substrate moisture content varies from dry to wet.

Materials and Methods: On 23 February 2015, 40 *Ilex crenata* 'Bennett's Compactum' liners were selected from 15 cell plug trays (Bennett's Creek Nursery, Inc., Suffolk, VA) and potted into #1 (2.7 L) containers (Model # T1G TL, Dillen Products, Middlefield, OH) using aged pine bark (Sun Gro Horticulture, Inc., Elizabeth City, NC) amended with 3.0 lb•yd^{-3} (1.8 kg•m^{-3}) ground dolomite (Rockydale Quarries Corporation, Roanoke, VA) and 3.0 lb•yd^{-3} (1.8 kg•m^{-3}) pulverized dolomite (Old Castle Lawn and Garden, Thomasville, PA). Plants were grown on an expanded metal bench in a greenhouse at Hampton Roads Agricultural Research and Extension Center in Virginia Beach, VA for 85 days. Plants were arranged in a completely randomized design. Plants were pruned to uniform baseline canopy architecture [approx. diameter of 4.7 inches (11.8 cm ± 0.4 SE); approx. perpendicular diameter 3.7 inches (9.3 cm ± 0.3 SE); approx. height of 4.3 inches (11.0 cm ± 0.2 SE)]. All plants received irrigation as needed and were fertilized with 3.3 oz (100 ml) of a 236 ppm (mg•L^{-1}) solution of Peters 20.0N-8.8P-16.6K (General Purpose 20-20-20, JR Peters Inc., Allentown, PA), periodically (approximately every 17 days) according to the standard cultural practices observed by commercial growers. Substrate physical properties (Table 1) were determined using the North Carolina State University poromoter method as described by Fonteno and Harden (11).

To ensure homogeneity all plants were thoroughly watered, and allowed to dry down to their target moisture content only prior to laboratory data collection. On the day of data collection, three plants from each moisture content treatment were randomly assigned to receive deionized water or mineral nutrient solution influent. In total, there were three groups receiving deionized water influent and three groups receiving nutrient solution influent, each consisting of one plant at each of the four moisture contents. In order to establish an initial pH and EC, an extra plant in each treatment was used to conduct a pour through as described by LeBude and Bilderback, 2009 (12). Initial pH and EC were 5.91 ± 0.06 and 213.6 μS•cm^{-1} ± 8.4 SE, respectively. All other plants were weighed to measure final moisture content prior to receiving water or fertilizer solution.

Moisture content targets were determined once roots began to explore the container volume, defined visually as the roots being 80% of the way down the container wall. Investigators identified 16% and 34% volumetric water content (38% to 56% moisture content) range to be similar to what would be observed under normal production conditions. Target weights were determined to be 2.48 lb (1125 g) for the lowest moisture content (MC) treatment (MC1, 38%) and 3.64 lb (1650 g) for the highest moisture content treatment (MC4; 56%). Target weights for remaining moisture content treatment [MC2 (44% and MC3 (50%)] were determined at equidistant points.

The aforementioned water-soluble fertilizer was added, 2.63 ounces (74.8 grams), to 4.5 gal (17 L) of deionized water in a 5-gallon (19 L) bucket. The resulting solution had an EC of ≈ 4000 μS•cm^{-1}. A sample was taken from each bucket to measure influent EC and pH using a bench top meter (Orion 4-Star) equipped with a 4-electrode conductivity cell (DuraProbe^{TM}) and pH electrode (Orion™ Model 91-72 Sure-Flow; Thermo Fisher Scientific, Beverly, MA). The influent diffuser and plant container was placed into a custom irrigation platform and leveled as described by Hoskins et al. (4). A 4-inch (10 cm) tall collar [7.5 inch (19 cm) diameter] was placed around each plant to ensure no loss of applied influent. Fertilizer solution or DI water was poured into the 2.5 quart (2.4 L) influent diffuser, with perforated bottom, and the water level was quickly brought a height of ≈1 inch (2.5 cm) while water was diverted away from the leveled container below. Once flow was stable at 2.69 gal•hr^{-1} (2.83 ml•sec^{-1}) the irrigation or fertigation event began (initiation time = 0) and delivered ≈ 0.80" (20.3 mm) over the course of two minutes and twenty-seven seconds before being diverted after completion of the irrigation or fertigation event.

Effluent was collected for a total of 900 seconds (15 minutes) after initiation. Fractionations were collected in increments of 0.85 oz (25 ml) for the first 1.69 oz (50 ml), and 1.69 oz (50 ml) thereafter. Time was recorded when first leaching was observed and when each incremental volume was reached. Electrical conductivity and pH of each fractionation was measured and recorded. Containers were allowed to drain for ≈13 minutes and then weighed to determine substrate final moisture content.

In order to determine root depth, the plant container was placed upside down in a tray, and substrate gently scraped off in layers beginning at the bottom of the substrate and the distance from top of the substrate surface to the first observed root measured. Rooting depth was 5.6 inches (14.2 cm ± 0.4 SE).

Results were subjected to analysis of variance or linear and quadratic regression (α = 0.10) and subjected to Tukey's range test (α = 0.05) where appropriate. Data was analyzed using JMP® Pro version 10.0.2 (SAS Institute Inc., Carey, NC).

Results and Discussion: Average effluent EC of containers receiving only DI water was 179 $\mu S \cdot cm^{-1}$ ± 7 SE. Initial moisture content or the quantity of leaching had little effect on the EC. Results indicate fertigation efficiency (i.e. decreased nutrient leaching) of *Ilex crenata* curvilinearly increased as pine-bark substrate moisture content increased from 38%, 44%, 50%, and 56%. This was most apparent when reporting the EC of leachate collected (Figure 1) when applying mineral nutrients. This was in part because observable leaching occurred much sooner (approx. 30 sec.) when substrate was drier (38% and 44%) than when at higher (50% and 56%) moisture content. When applying water only, leaching was observed at approximately 32 seconds when substrate at low moisture content versus 89 seconds when initial substrate moisture content was 50% or greater. When applying solute, the time to observed leaching increased with increasing initial moisture content (31, 40, 72, 90 seconds from 38% to 56% MC).

The authors hypothesize mineral retention is aided by a more uniform distribution of water (and mineral nutrients) as the result of increasing hydrating efficiencies at higher initial moisture content as observed by Fields et al. (3). This is believed to be a result of decreased preferential flow at increasing moisture content; whereas, solute (water and mineral nutrient) retention and distribution in the container was greater when fertigating pots pre-hydrated (4). In conclusion, these results suggest nutrient leaching can be reduced by fertigating when container moisture content is relatively high, rather than relatively low. More research is needed to see if cyclic irrigation alone can mitigate issues with channeling and subsequent resource inefficiencies.

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Table 1. Physical properties for a substrate comprised of 9:1 (by vol.) Pine-bark : sand using the NCSU porometer method.

D_b	TP	CC	AS
0.24	77	53	24

D_b = Bulk density g•cc^{-1}.
TP = Total porosity. Percent of substrate vol. comprised of pores or void space. (TP = Volume of water to saturate substrate)
CC = Container capacity. Percent of substrate vol. comprised of water after free drainage occurring as a result of gravity and atmospheric pressure. (CC = TP – volume of water drained after saturation)
AS = Air Space. Percent of substrate vol. comprised of air at container capacity. AS = TP - CC.

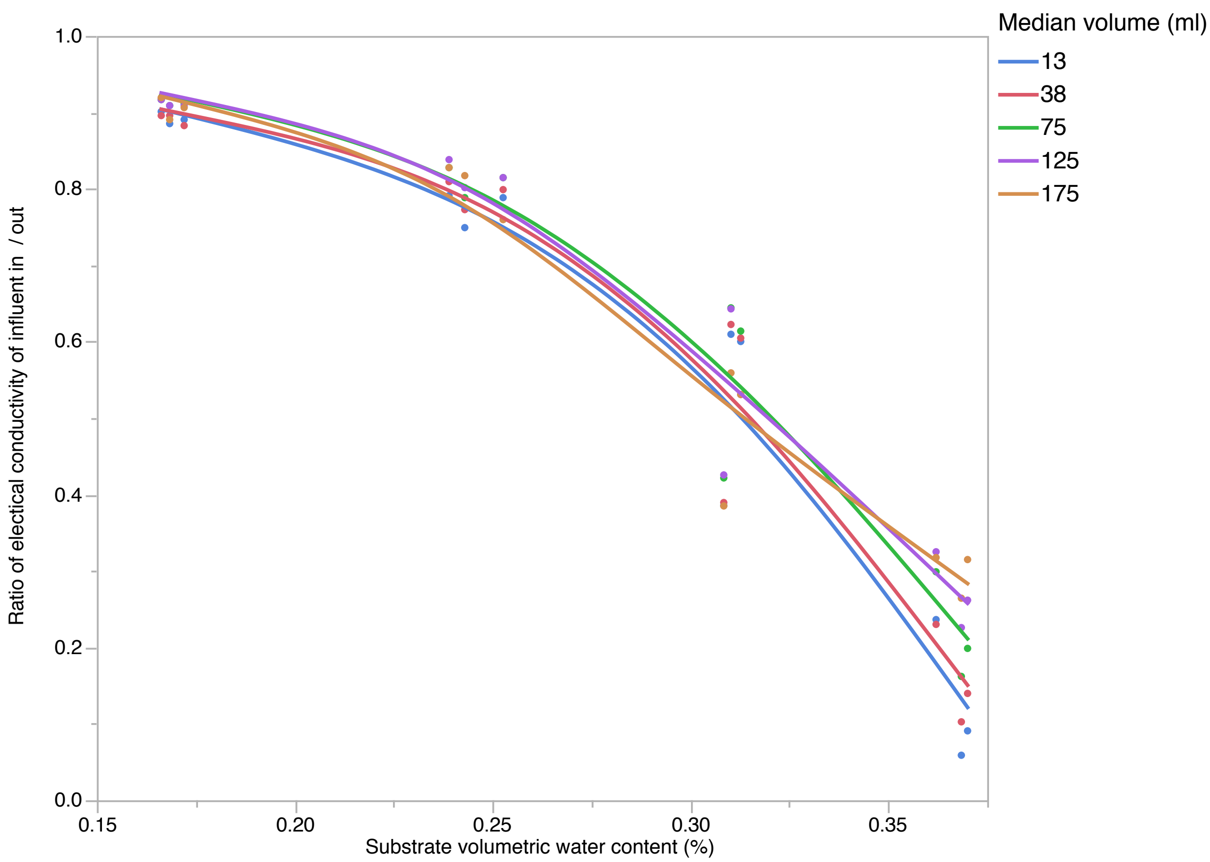

Figure 1. Influent / effluent electrical conductivity ratio of incremental leachate fractions when fertigating (mineral nutrient solution having an electrical conductivity of 3820 µS•cm^{-1}) *Ilex crenata* growing in a pine bark substrate with varying water content.