# Fertilizer Movement in Nursery Containers: What Happens during Irrigation?©[1]

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**Recommendations for the efficient use of fertilizer resources in containerized plant production systems are largely based on season-long nutrient leaching dynamics under the impact of various fertilizer and irrigation management practices. To date, little research has been conducted to understand the principles of water and fertilizer movement through a nursery container during irrigation and how these principles may impact nutrient fate. A saturated solute transport study was conducted by passing a fertilizer solution and deionized water through a saturated pine bark substrate and measuring the electrical conductivity of the drainage. The result is a breakthrough curve, which is helpful to both growers and researchers in understanding the movement of water and fertilizers through the highly porous and relatively inert substrates used in containerized ornamental crop production.**

## INTRODUCTION

Mineral nutrients are conventionally applied to containerized ornamental crops via irrigation as soluble salts dissolved in irrigation water (i.e., fertigation) or by a plastic-encapsulated fertilizer source (i.e., controlled release fertilizer; CRF) which release nutrients over long periods of time (i.e., months). Water is the medium by which these nutrients are made available to plants. Water applied via irrigation fills substrate pores and either carries dissolved nutrients to roots or hydrates CRF prills, leading to the diffusion of nutrients from inside the prill to the surrounding water. Between irrigation events, roots will absorb a portion of the available water and nutrients. Pore water not absorbed before the next irrigation is displaced by newly applied water, thus being leached from the substrate into the surrounding environment.

Our current understanding of nutrient fate in containerized ornamental crops has been based on theory of CRF nutrient release (Adams et al., 2013), plant absorption (White, 2012), and season-long nutrient release (Newman et al., 2006). However, there is limited experimental research investigating nutrient fate (availability, uptake, and leaching) during irrigation events. To understand the principles of water and solute (i.e., fertilizers dissolved in water) transport we may utilize well-established procedures from the study of soils (Skaggs, 2002). However, the physical properties of soils differ from that of bark-based substrates. Particle sizes for major soil groupings, as classified by the U.S.D.A., are sands (<2-0.05 mm), silts (<0.05-0.002 mm), and clays (<0.002 mm) and porosities may range from 30-60% for most soils (Hillel, 1998) depending on composition. In contrast, the particle sizes of the substrate used in this study are 8.0% > 6.3 mm, 27.6% 6.3-2 mm, 37.9% 2-0.71 mm and 26.5% < 0.71 mm by weight with an average total porosity of 73.5%. Our objective is to understand movement of dissolved nutrients entering and being displaced from a bark-based substrate using traditional methodology from soil science.

## MATERIALS AND METHODS

On 19 June 2013 a bark and sand (9:1, v/v) substrate [bulk density (Db) = 0.32 $g{\cdot}cm^{-3}$] was potted into trade gallon (2.7 L) nursery containers (Myers Industries, Middlefield, Ohio). Containers were placed on an outdoor gravel pad at the Hampton Roads Agricultural Research and Extension Center and were subjected daily to a 15-min overhead irrigation (0.5 in./h, SD = 0.1). Substrate from five containers was pooled into

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one composite sample and allowed to equilibrate overnight in a sealed container before use to ensure a more evenly distributed moisture content.

The experimental unit was a 30-cm acrylic column (7.75 cm i.d.; 8.9 cm o.d.; vol. = 1.415 L ≈50% of a trade gallon nursery container) enclosed by polyvinyl chloride (PVC) flat caps at each end. Barbed fittings (3.5 mm i.d.) in each cap created an inlet and outlet point at each end of the column. The vertically oriented column was attached via 5/16-in. Tygon tubing to a three-way valve and two mariotte bottles, one containing deionized (DI) water and the other containing a fertilizer solution comprised of nitrogen (N), phosphorus (P) and potassium (K) with an electrical conductivity (EC) of 0.33 $mS \cdot cm^{-1}$. Mariotte bottles allowed for the maintenance of constant pressure as the fluid level in the bottles decreased. Figure 1 depicts the physical setup of the experiment.

The column was packed with substrate using a modified version of the NCSU porometer procedure (Fonteno, 2003). The sample column was joined to a 15-cm sealed-base column below and a 30-cm column above to create a 75-cm packing apparatus. This apparatus was loosely filled to the top with substrate and dropped 7 times from a height of 17.5 cm to achieve a uniform Db in the middle column. Top and bottom sections of the packing column were removed and the substrate surface at each end was leveled, covered with a circular window screen to minimize sediment loss and capped. Once packed, the column was placed such that the inlet was on the lower end of the column allowing the substrate to be saturated from below with DI water. Saturation was paused for 5 min at the 10 and 20 cm heights to allow for moisture equilibration. The column was then returned to an upright position (inlet at the top) and steady state flow of DI water through the column was established minutes based on the difference in height (z) between the column outflow valve and the base of the mariotte bottle air inlet tube ($\Delta z$ = 54.45 cm). Prior to initiating the experiment, the steady state flow rate of DI water was determined to be 4.6 $ml \cdot s^{-1}$, SD = 1.5 and effluent (drainage) was confirmed to have no residual salts from the pore water or bark using a HI 9813-6 pH/EC meter (Hanna Instruments, Woonsocket, Rhode Island). Next, a two-step breakthrough experiment was initiated by infiltrating two pore volumes (PV = volume of water held in the pore spaces = 1.04 L) of fertilizer solution into the DI saturated column (Step 1) after which the influent was returned to DI water (Step 2) until the effluent was free of any residual fertilizer solution (EC = 0). The final flow rate was determined to be 4.4 $ml \cdot s^{-1}$, SD = 1.5.

A total of 38 samples were collected in 150-ml increments for each of three repetitions and analyzed for EC. Mean and standard error of EC were calculated and are reported graphically in Figure 2 as the relative EC ($C/C_i$), where C = actual EC for a given sample and $C_i$ = EC of the input solution. In addition, theoretical piston flow was calculated based on the porosity of the substrate and column dimensions (Skaggs, 2002). Graphs in Figure 2 are breakthrough curves (BTC) overlaid with the theoretical piston flow model.

## RESULTS AND DISCUSSION

The BTC in Figure 2 illustrates the dramatic difference in the observed solute (i.e., fertilizer) transport from the piston flow model. Fertilizer solution in Step 1 quickly begins to leach at 0.4 PV demonstrating the rapid movement of water through the column before filling all the pores. Effluent EC was 80% of the fertilizer solution at the first pore exchange and did not reach full concentration until 2 PV. Step 2 produced similar results with the infiltrating DI water reaching the outlet at 0.3 PV. Effluent EC was 10% of the fertilizer solution at 1 PV and did not fully diminish until 1.6 PV.

To understand the BTC deviations from piston flow it is first necessary to understand that in a conceptualized piston flow model, a sharp boundary (commonly called a “front”) exists between the input solution and the solution already in the pore spaces. As the input solution is delivered and effluent is simultaneously drained, the front moves toward the outlet like a piston through a cylinder. The arrival of the front at the end of the cylinder is reflected by a sudden jump in relative effluent concentration from either $C/C_i = 0$ to 1 in Step 1 or $C/C_i = 1$ to 0 in Step 2. This should occur upon the displacement of 1 PV.

It is well known that water transport is affected by pore/channel size and the degree to which they are interconnected (Ma, 1997). Substrates with an array of particle sizes contain an array of pore/channel sizes where water can more easily flow through large pores and arrive ahead of the conceptual piston. Conversely, smaller pores and channels retard the flow of water through allowing water to arrive after the piston. Chemical processes, such as the diffusion of nutrients in the presence of a concentration gradient, may also slow the progression of influent behind the piston. In Step 1, the nutrients from the relatively concentrated input solution diffuse into pore water and may take longer to fully displace, diffuse, and reach full concentration. Step 2 is similar, however the gradient is reversed. Furthermore, the effect of chemical interaction between the fertilizer solution and the bark should not be ignored. Though difficult to quantify using EC measurements, the exchange capacity of bark can interact with both cations (K, $NH_4$) and anions ($PO_4$) and retard their movement through the system.

Saturated conditions are rare in containerized nursery production systems. However, analysis of saturated solute transport is an easy tool to help understand some of the principles of water and fertilizer movement during irrigation. These results indicate that even though the physical properties of pine bark substrates may fall outside the spectrum of a typical soil, the fundamental tools used in soil science can be utilized to better understand soilless substrate production systems. Additionally, further research is warranted to explore the dynamic behavior of water and fertilizers during irrigation. The study of wetting front patterns and the transport of fertilizers through an unsaturated system has the potential to provide information that would lead to more informed management decisions in nurseries. Research herein will allow scientists and growers to better understand solute movement in highly porous, relatively inert substrates under the various water flow conditions observed in ornamental crop production.

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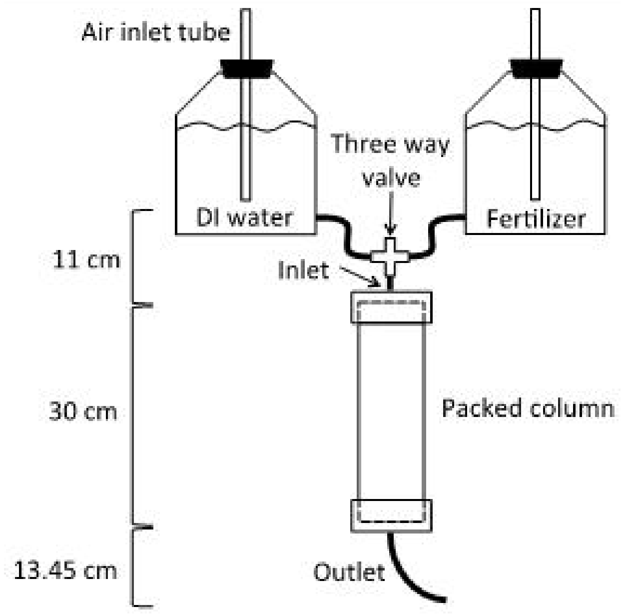


Fig. 1. Physical setup of the saturated column. Mariotte bottles allow for constant pressure through the system as the water level in the container decreases. A three-way ball valve allows for the seamless transition between DI water and fertilizer solution sources.

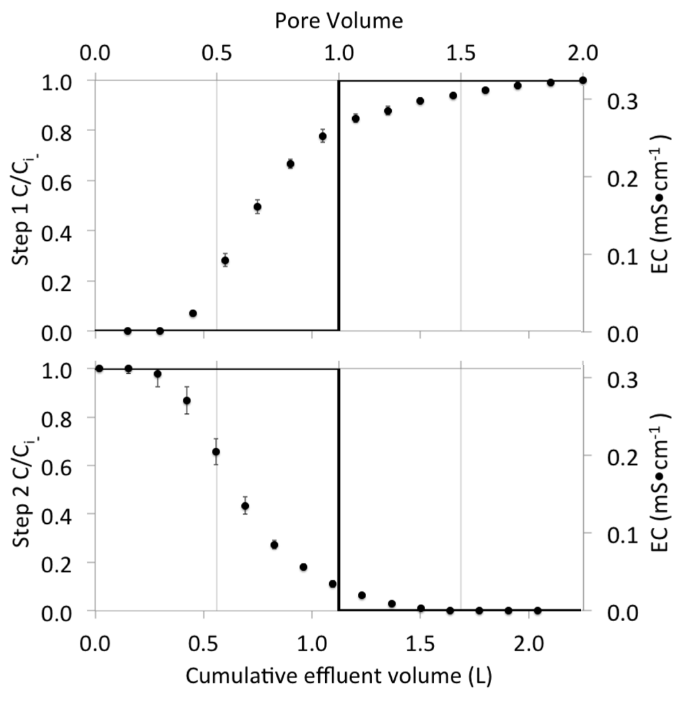


Fig. 2. Breakthrough curves showing the relative concentration (electrical conductivity) of the effluent as a fertilizer solution is infiltrated into a saturated column (Step 1) and as deionized water is infiltrated (Step 2) into the same column immediately after step 1. Solid line represents the piston flow model.