Water Management

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Section Editor

Characterizing Water Uptake Efficiency of Peat and Pine Bark Substrates by Two Irrigation Delivery Methods

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Index Words Subirrigation, pine bark, hydrophobicity, capillarity, macropore, micropore

Significance to Industry Substrate composition and architecture are underlying variables in the water use efficiency of greenhouse substrates. These variables can play a pivotal role in the effectiveness of the irrigation method used as the industry continues to move into new, more cost effective materials. Understanding hydration potential, water holding, and water movement through the substrate can allow growers to understand the ability of the substrate to retain and release water to the plant while maintaining a healthy irrigation pattern. This information can help growers reduce their water consumption and nutrient use over the course of producing the containerized crop. Thus, the following research aims to better characterize the differences each substrate composition can have based on irrigation strategy and material composition. Realizing the monetary benefits aligned with reducing water consumption, and possible future water regulations, producing a profitable crop with less irrigation and few changes to the overall process would be a great advantage to nursery growers. The dynamics of a substrate need to be understood to bring these notions to the forefront of the industry.

Nature of Work Freshwater is a renewable resource, but quantity is based solely on location of operation. In 2009, the USDA released an estimate that 20,000 acres of land are currently devoted to commercial greenhouse production in the US (U.S. Department of Agriculture (USDA), 2009) add to that the United States Geological Survey reported that 40% of the freshwater used in the US is for crop irrigation alone. In terms of acre per day, a container nursery may consume up to 19,000 gallons during the peak of growing season (2). With the shift to containers, fertilization and irrigation are necessary frequently due to the small volume of substrate for growth (1). Container plants are typically grown in peat, bark, or coir amended with perlite and wood based products. Soilless substrate components are known to have significantly higher air space than that of their mineral soil counterparts, which results in more frequent irrigation than field grown products. Without that understanding, unnecessary excess water is used once or multiple times a day to reduce the perceived risk of water stress and reduced yield (3). Efficiency (the amount of water retained in the container and available to the plant / total water applied) being the main purpose for growers to choose any irrigation method, overhead at its best with minimal spacing between pots is near 80% (4) with preliminary testing showing subirrigation at 65%. Water held in the container is available to the plants only if it comes in direct contact with roots. Generally, if water passes through the macropores of the substrate, which require less tension for the water to be released, but the water isn't in contact with the roots, it isn't as beneficial to the plant unless the water

is mobilized. Factors such as particle size, pore size, and substrate hydrophobicity effect the substrates ability to take up water and can change the efficacy of each irrigation method.

Our study examined how substrate architecture and materials can influence the water uptake efficiency. Using both subirrigation and overhead drip testing methods and materials such as sphagnum peat moss or pine bark which may allow higher percentages of water in the container available for plant uptake. Better movement and retention will ultimately reduce the amount of water needed to produce a viable crop as the plant will need to expend less energy to take up water, minimizing stress on the plant and saving the grower on irrigation costs.

The irrigation practices being tested were subirrigation as well as overhead irrigation using an Ebb and Flood irrigation table (Hawthorn Hydroponics, Vancouver WA) 2 ft wide by 4 ft in length and the NCSU Wettability method (5). The former process used water pumped into the bench via piping from a faucet and controlled through a series of gate valves connected to the bench. Water flow rate was also controlled through a gate valve by (simply) opening it to points documented for adequate flow. To be able to control the height of the water while also having a steady flow into the bench, copper pipes were measured and cut to the right lengths to allow water to be held at height of 1" (2.54 cm). Substrates were tested using equipment consisting of a transparent cylinder, 5 cm diameter x 15 cm height, with a mesh screen attached to one end, using rubber pressure plate rings to allow for exact positioning of the vial above the substrate surface to control hydraulic head (5). Base substrate components being tested were sphagnum peatmoss (Premier Tech, Canada) and pine bark (Pacific Organics, NC, PM2) and were further blended with 20% (by volume) perlite, hammer-milled pine chip and coconut coir as well as a pine bark – 10% sand mixture (Builder's grade, NC). All of which were further moistened to 2.0 mass wetness (MW), then air dried down to 1.0 and 0.5 MW, representing moisture contents of 50 and 33% by weight.

Cylinders were then packed by weight, keeping all 4 reps of each substrate moisture content within 5% of each other and then packing them down to a pre-measured 10 cm of height to ensure similar bulk densities. Cores were then places on an elevated mesh screen to optimize surface area exposure to water at 1.7 cm off of the base of the flood bench which was included in the water level calculation so that water was at 2.54 cm above the base of the cylinder. For the latter method (Wettability), substrates used and packing techniques were identical to ensure a proper comparison.

As stated in the wettability method (5), substrate cylinders were attached to ring stands at set heights (Fig. 1a) with a vial fitted with O rings and 5 holes in the base sitting above the substrate surface. The holes in the vial were there to act as a diffuser of water and reduce impact harshness on substrate surface. Water was passed through the cylinder at a rate of 2-3 liters per hour, controlled by the funnel stopcock. Each hydration event consisted of 200 mL of water (10 events total), effluent water was captured and moisture retained was calculated by subtracting water input from output.

To be able to show an accurate comparison, subirrigation testing was done in a 10 event setup with each event calculated to take a similar timespan as those with wettability. Five minute intervals at 2.54 cm water height and a total of 10 events was the final setup.

Container capacity was tested for both irrigation methods by using the NCSU Porometer manual (6). After the final hydration, the sample cylinder was removed and weighed, then placed into a Buchner funnel with holes described by the NCSU Porometer manual (6). Water was slowly added from the bottom in a "1/3 at a time" stepwise manner until water reached the top of the substrate surface. After 15 minutes, water was drained from the sample and given 30 minutes in total to drain before the sample is removed and weighed. Samples are then oven-dried at 105°C for 24-48 hours.
The experiment was a completely randomized design. Using SAS (Cary, NC), statistical mean separation, Tukey's HSD, and regression curves were done with LSD (p 0.05).

Results and Discussion: Final volumetric water content showed very little significant difference statistically, although the data seems to show surprising similarities between substrates. Wood in its various forms is being implemented as a perlite substitute for cost purposes, with wood being manipulated in different refining processes. Perlite and wood, regardless of irrigation practice are similar in both container capacity and volumetric water content. The aforementioned results can be explained by the ability of both perlite and wood to increase pore size and facilitate better water movement without jeopardizing weight/density. The addition of coir to peat was intended to promote the hydrophilic characteristics of coir on a material like peat that trends toward hydrophobic in low moisture environments. Using that mixture of fine textured materials increased uptake through subirrigation while showing little impact in overhead application (Table 1.).

Using sand increased both weight and bulk density, but with coarse pine bark, the capillary movement increased allowing more water to be held in the pores than that of overhead irrigation which tends to work through macropores. Peat's hydrophobic properties arise in moisture contents below 40% and the subirrigation value of a 15.45% final VWC represent the stark difference in its hydration potential at low moisture contents between overhead and subirrigation. There is little to no movement in peat unless irrigated from above, allowing water to channelize through the substrate. Perlite amended substrates had no significant difference between irrigation strategies, evident by the similar final volumetric water contents and container capacity values.
Volumetric water content curves allow us to infer the differences in flow rate through each irrigation strategy and demonstrate the ability of each substrate. For a substrate composition of peat-coir at moisture content 50% (Fig. 2 A & B), we can infer that the hydraulic conductivity of the finer materials is greater that coarser materials similar to the pine bark mixes.

Particle size distribution needs to be done on these mixes to further investigate the physical properties and their abilities to capture and move water through the cylinder.

As a result of higher volumetric water content levels in overhead irrigated cylinders, the authors hypothesize that the increased air space accompanying these mixes allowed more favorable conditions for water to move through the substrate than those subirrigated. Further research is needed to better understand the pore structures created by using different materials to amend substrates, and further refine the irrigation strategies necessary for optimal hydration efficiency.

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Table 1. Container capacity, bulk density, and volumetric water content (after 10 hydration events) of peat, pine bark, and amended mixes.

	Subirrigation			
Substrate	Moisture Content[z] (g/g)	Container Capacity (% vol)[y]	Bulk Density (g/cm^3)x[c]	Final Volumetric Water Content (%)[w]
Peat	33%	0.49 ba[v]	0.15 bc	15.65 bc
	50%	0.58 ba	0.13 bc	26.04 bc
Pine Bark	33%	0.42 b	0.19 bc	26.11 bc
	50%	0.51 b	0.20 bc	40.65 bc
Peat-Coir	33%	0.52 ba	0.16 bc	26.19 bc
	50%	0.57 ba	0.14 bc	36.88 bc
Peat-Wood	33%	0.62 ba	0.15 c	21.20 c
	50%	0.66 ba	0.09 c	41.13 c
Peat-Perlite	33%	0.53 ba	0.07 c	33.00 c
	50%	0.51 ba	0.14 c	35.96 c
Pine Bark-Wood	33%	0.56 ba	0.17 bc	23.16 bc
	50%	0.65 ba	0.12 bc	42.87 bc
Pine Bark-Sand	33%	0.52 ba	0.31 a	33.27 a
	50%	0.66 ba	0.31 a	48.74 a

Table 1.(Continued) Container capacity, bulk density, and volumetric water content (after 10 hydration events) of peat, pine bark, and amended mixes.

Substrate	Moisture Content[z] (g/g)	Container Capacity (% vol)[y]	Bulk Density (g/cm³)[x]	Final Volumetric Water Content (%)[w]
		Overhead Irrigation		
Peat	33%	0.63 ba	0.15 bc	36.58 bc
	50%	0.53 ba	0.13 bc	38.63 bc
Pine Bark	33%	0.43 ba	0.18 bc	33.79 bc
	50%	0.51 ba	0.19 bc	33.70 bc
Peat-Coir	33%	0.66 ba	0.15 bc	36.11 bc
	50%	0.68 ba	0.13 c	38.60 c
Peat-Wood	33%	0.61 ba	0.16 bc	35.82 bc
	50%	0.67 ba	0.14 bc	38.57 bc
Peat-Perlite	33%	0.45 ba	0.17 bc	34.88 bc
	50%	0.56 b	0.18 bc	33.89 bc
Pine Bark-Wood	33%	0.80 a	0.14 bc	37.82 bc
	50%	0.75 a	0.16 bc	36.03 bc
Pine Bark-Sand	33%	0.72 ba	0.28 ba	24.21 ba
	50%	0.71 ba	0.22 b	29.89 b

[z]Moisture content is the pre-determined amount of moisture by volume in the substrate.
[y]Container capacity is percentage of the sample volume occupied by water after allowing the sample to drain for 30 minutes.
[x]Bulk density is the dry weight of the sample (solid particles) ÷ total volume of the sample. (M_s/V_t).
[w]Volumetric water content is a percent of the pore spaces occupied by water
[v]Means analyzed using Tukey's Honestly Significant Difference (HSD), and different letters represent statistical differences with α=0.05.

Figure 1: A) Photograph of the NCSU Wettability Manual setup with beakers collecting effluent from cylinders after an irrigation event and B) Subirrigated samples in an Ebb and Flood table during an irrigation event.
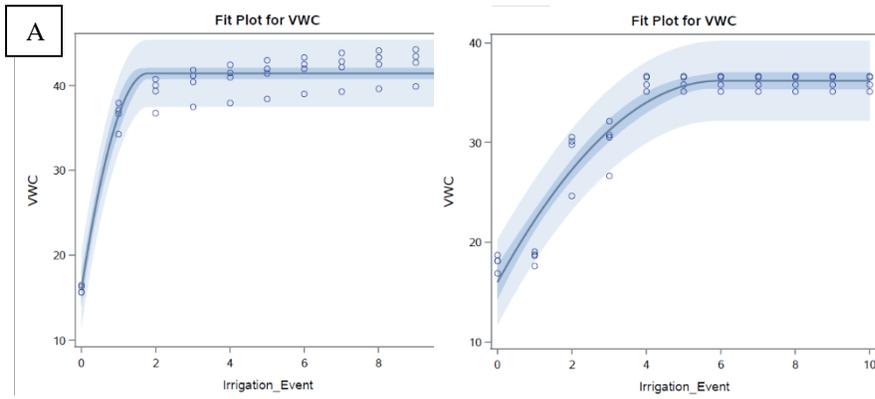
Figure 2: Percent volumetric water content over 10 events on Peat-Coir substrates at 50% moisture content. A) subirrigated sample and B) overhead irrigated sample.

Tracking Nitrogen from Pot to Reservoir: A SC Nursery Case Study

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Index Words Phosphorus capture, eutrophication, filtration

Significance to the Industry Irrigation return water from nursery and greenhouse operations often contains nitrogen (N) that may be released offsite if the water is not treated or reused. Excess N can contribute to degradation of water quality, as the growth of aquatic weeds and algal communities are supported when N and other nutrients are available. Conventionally, nurseries tend to design water infrastructure to move water off production areas as quickly as possible. Advanced water management infrastructure can facilitate quick movement of water from production areas while integrating sediment and nutrient best management practices to improve water quality. To quantify the influence of various design features, we monitored a plant nursery for two and a half years, concentrating on seven sites: the irrigation source, irrigation runoff receiving areas, vegetative channels, and three ponds in series. We quantified N movement throughout the water management infrastructure. Vegetative buffers and channels are simple, yet effective infrastructure that serve to slow water and remediate N. Reservoirs (tailwater catch basins) in series, rather than a single large reservoir, help to facilitate continued N reduction and enhanced water quality. In future work, we will evaluate how these same site features influence sediment, phosphorus, and pathogen fate. These results will help growers design and redesign water movement infrastructure to meet water quality goals.

Nature of Work Nitrogen availability is critical for plant growth for producing both plants in containers and, unfortunately, growth of aquatic weeds and algae. Excess N availability in irrigation return water, especially if the water is released offsite, can result in degradation of aquatic ecosystems (e.g., harmful algal blooms) [1]. The water conveyance infrastructure at nursery and greenhouse operations helps move irrigation return flow and stormwater runoff from production areas, by conveying it offsite or to tailwater catch basins and reservoirs, from which it can be reused for irrigation [2, 3]. It is desirable to reuse N present in irrigation return flow, but if the water is released offsite, the N remaining in water needs to be reduced to a level below environmental concentrations of concern (Total Maximum Daily Loads for a specific water body). Nurseries have typically reduced concentrations of N in water leaving their operation to

comply with drinking water standards, when no other regulatory limits were available as endpoints. Drinking water N limits (10 ppm nitrate-N) are much higher than the concentration of N required to classify a body of water as eutrophic (0.6 to 1.5 ppm nitrate-N) [4, 5].

The influence of water conveyance infrastructure design on the fate of N within nursery production systems is poorly understood. There is also little information available regarding integration of design features and potential for synergistic effects of holistic infrastructure choices (e.g., several smaller ponds instead of one large pond) on contaminant management within irrigation return flow and stormwater. Copes et al. [5] and Zhang et al. [6] characterized water quality in eight recycling irrigation reservoirs in nurseries in the MidAtlantic Region of the U.S., yielding information on water quality (physicochemical) and chlorophyll dynamics within individual irrigation reservoirs. Yin and Shan [7] described use of multi-pond systems to manage diffuse P contamination from agricultural sources. Majsztrik et al. [8] detailed the varied treatment technologies available to manage contaminants in water. However, the treatment technologies described were studied independently from each other, thus it is difficult to ascertain the impact that treatment technologies have on contaminant fate when used in sequence with each other (a treatment train). The goal of this study was to (1) quantify the volume of water (gal) and mass of N (g) that moved through the water infrastructure at a small nursery and (2) determine how the connectivity of water infrastructure influences changes in water quality – as evidenced by the fate of N in the system.

Research was conducted from July 2016 – November 2018 at a 10-acre retail/ production nursery in the Piedmont region of SC. Irrigation water is pumped from a creek and applied via overhead irrigation to open-air retail beds and shade houses (Fig. 1). The retail greenhouse, production greenhouse, and open-air production beds were irrigated using municipal water. French drains enabled fast movement of irrigation and stormwater from all production area surfaces. Irrigation return water flows through the French drains to a vegetated channel that runs along two sides of the nursery entering the vegetated channel parallel to the production area near the creek and middle of the vegetated channel. Water flows from the vegetated channel into a series of 3 hydraulically connected ponds, meaning that water can flow either forward into the ponds or backward into the vegetated channel, save for the outlet from Pond 2 into Pond 3 that does not permit backflow. Monitoring equipment including seven automated water samplers (Teledyne ISCO, Lincoln, NE) and seven water quality sondes (YSI Inc., Yellow Springs OH) that continuously logged temperature ($°C$), pH, specific conductance (µS/cm), and dissolved oxygen (ppm). Water samplers were programmed to collect samples before (one sample 10 minutes prior to irrigation initiation), as well as during and after (five samples at 10-minute intervals followed by six samples at 20-minute intervals) irrigation events. After purging the line twice, a single 1-quart water sample was collected, with 12 samples collected for each sampling event at each sampling location. Samples were transported on ice and then filtered and frozen at -20 $°C$. Water samples were analyzed using Ion Chromatography, with ionic N values representing the sum of ammonium-N, nitrite-N, and nitrate-N. Data were analyzed via

Standardized Least Squares model using JMP 14.3 (SAS Institute Inc., Cary, NC). Mean comparisons were delineated using the LSMeans procedure with Tukey HSD ($p <$ 0.05). Monthly data were averaged over the sampling period.

We quantified the volume of water flowing through the water infrastructure between Pond 2 and Pond 3 using a V-notch weir and then normalized that volume to each sampling location by time so that we could calculate nutrient load. All volume measurements were derived from this single point as that is the only point in the water infrastructure where the ponds and VCs were not hydraulically connected. The volume of water that flowed through the system per irrigation event ranged from 3,500 to 13,500 gal per irrigation event in the first quarter (Q1) (Jan – Mar), 95,786 to 102,000 gal in Q2 (Apr - Jun), 22,578 to 31,500 gal in Q3 (Jul – Sep), and 2,572 to 2,700 gal in Q4 (Oct – Dec) (Fig. 2). With these summative volumes, we calculated inorganic N load when we simultaneously were able to measure water flow through the system at the V-notch weir, and also collected samples from irrigation events. The cumulative load of inorganic N into the system at VC2 was ~9870 g for the sampled irrigation events over the two years; the load of ionic N that left Pond 3 was 356 g for sampled irrigation events over the two years.

Inorganic N dynamics throughout the system were consistent from sampling point to sampling point over the season (Fig. 3). The most inorganic N was loaded into the system consistently at Vegetative Channel (VC) 2 ($p < 0.001$), where irrigation return water entered from production and retail greenhouses and production beds. The average inorganic N concentration at VC2 was 10.0 ± 1.08 ppm (range: 4.39 ppm in Dec to 18.7 ppm in June). Inorganic N concentrations were similar at VC1, VC3, Pond 1, and Pond 2 (1.05 ± 0.09 ppm); and percent reduction in inorganic N concentration from VC2 ranged from 69% at VC3 in Aug and Sept to 99% in Pond 2 in Nov. The average inorganic N concentration at the creek sampling location (upstream of the nursery) was similar to that of the inorganic N concentration measured when water exited Pond 3 (0.49 ± 0.07 ppm ionic N). Percent reduction in inorganic N concentration from VC2 to Pond 3 ranged from 82% in May to 99% in Jun and Nov.

The connectivity of water infrastructure at this nursery increased the length of time that a given unit of water stayed within the system, increasing the potential for remediation processes to begin to remove nutrients carried from production areas after irrigation events in irrigation return flow. The relatively short distance (100 ft) between VC2 and VC3 was adequate to facilitate removal of between 69 and 95% of the inorganic N loaded into the system. At each additional sampling point, inorganic N concentration continued to decline. With strategic installation of consecutive treatment technologies, paired with increasing distance and/or depth to increase the residence time of water in the system, N removal was accomplished. Vegetated channels and serial pond designs are shown to be best management practices for nursery crop production. Growers should consider use of paired, sequential treatment technologies (such as VC paired with multi-pond catchment systems) to manage N within their water, especially if water leaves their operation either generally or during storm events only.

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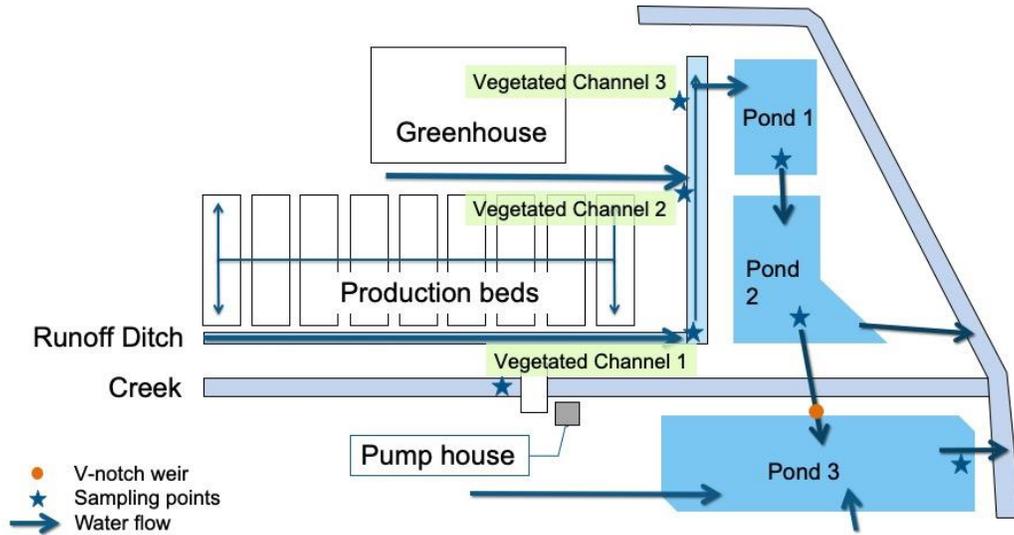
Figure 1. Water flow path at a SC nursery. The seven water sampling points are noted by the stars. The blue arrows indicate the direction that water flows through the water infrastructure at the nursery. The orange dot designates the v-notch weir where water velocity and height were measured to quantify the volume flowing through the interconnected water infrastructure.
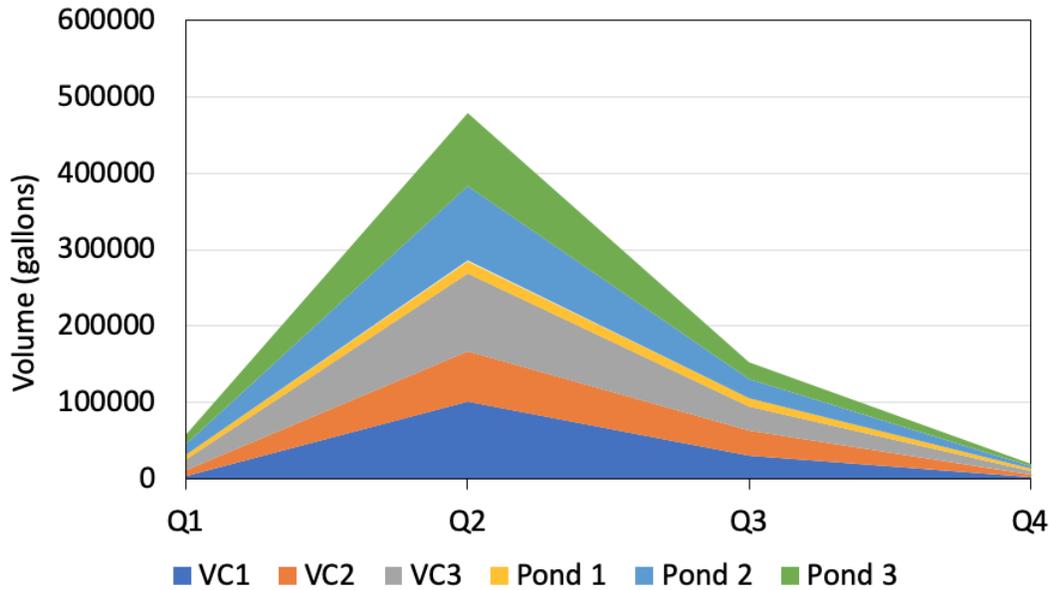

Figure 2. Average cumulative volume of water that flowed through each sampling site over a 12 hour sampling during each quarter. VC = Vegetative Channel, Q1 = Jan – Mar, Q2 = Apr – Jun, Q3 = Jul – Sep, and Q4 = Oct – Dec.
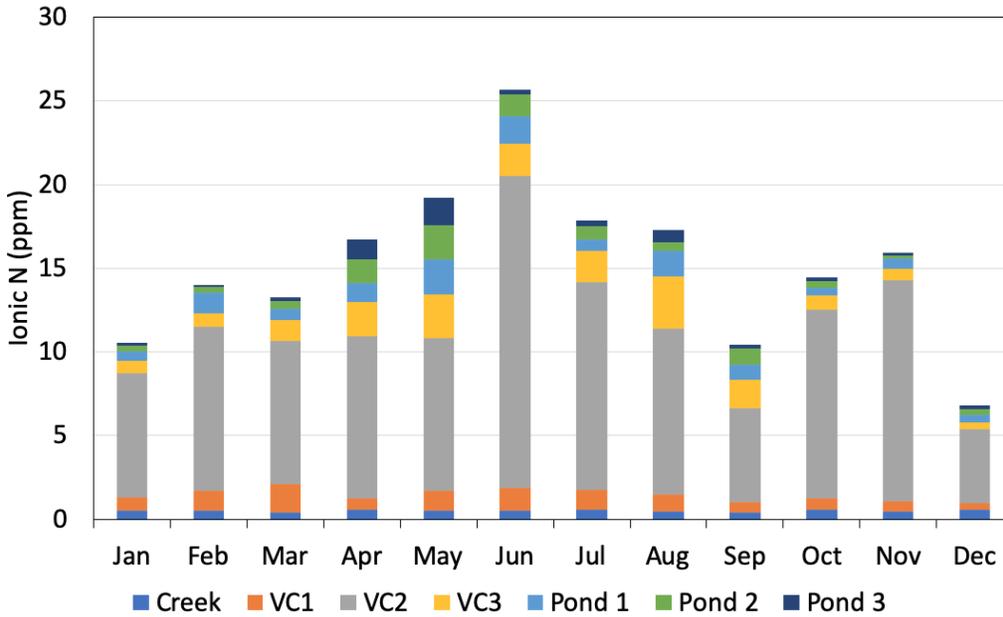
Figure 3. Average inorganic nitrogen (ammonium + nitrite + nitrate) concentration in water samples collected at seven locations across a nursery in the upstate of SC over two years. VC = Vegetative Channel.