A Case Study of Irrigation Pondwater and Soilless Substrate Quality across Nine Large Nurseries in Eastern Virginia

Kristopher S. Criscione[1]

Keywords. **chemical, container, nursery, physical, resources**

Abstract. Nursery producers depend on clean irrigation and efficient soilless substrates to successfully produce salable plants. Little information is available regarding the quality of irrigation and pine bark used in large eastern Virginia nurseries, despite the impact eastern Virginia nurseries have on Virginia horticulture sales. The objective of this case study was to investigate whether large nurseries located in eastern Virginia maintained irrigation and substrate quality within recommended standards. Irrigation pondwater (n = 8) samples were collected and tested for chemical properties, including pH, electric conductivity, alkalinity, total suspended solids, hardness, calcium, iron, and sodium. Additionally, pine bark-based substrates (n = 9) were collected and tested for substrate physical properties, including water storage, air-filled porosity, total porosity, and bulk density. The results of this case study showed that nursery irrigation pondwater had lower alkalinity values than recommended standards, while pine bark-based substrates used by large nurseries slightly exceeded air-filled porosity recommendations. However, all other parameters measured were generally within acceptable recommended standards.

The Virginia horticulture industry generated nearly $370 million of US farmgate sales and comprised approximately 1500 farms in 2022 (US Department of Agriculture 2023). Virginia nurseries contributed approximately 41% of Virginia horticulture sales (~350 farms) and was nationally ranked 16th in nursery production in 2022 (Stallknecht and South 2025). Large nurseries located within eastern Virginia account for a sizable portion (~2800 acres; Virginia nursery producers) of the total acreage of nursery stock grown in the state (~9100 acres) (Stallknecht and South 2025).

Nursery operations rely on consistent and clean resources to produce container plants and ensure production fruition, including high-quality irrigation and soilless substrates (Raviv et al. 2019). Many eastern Virginia nursery growers use on-site retention ponds to collect and recirculate leached irrigation water with the aim of reducing groundwater consumption and limiting runoff (Fain et al. 2000; Virginia nursery producers). Additionally, nearly all outdoor Virginia nursery growers produce container crops in a pine bark-based substrate (Virginia nursery producers).

Poor water quality in irrigation retention ponds such as adverse pH levels, undesired salts, or imbalanced minerals can lead to crop losses, nonuniform growth, and costly setbacks (Fulcher et al. 2016). Additionally, inconsistent substrate quality, including nonideal physical properties, such as suboptimal water storage or air-filled porosity (AFP), can result in superfluous irrigation applications and exacerbate fertilizer loss, negatively impacting plant growth and production sustainability (Mathers et al. 2007).

Despite the importance of irrigation water and substrate quality for successful production, limited information is available regarding the current state of irrigation pondwater and soilless substrates used by large nurseries in eastern Virginia. The objective of this case study was to investigate whether large nurseries located in eastern Virginia maintained irrigation and substrate quality within recommended standards.

Materials and methods

Samples of irrigation pondwater (n = 8) and soilless substrates (n = 9) were collected from willing eastern Virginia nurseries. Individual nurseries are not identified because of privacy concerns. The nursery operations ranged across six counties (Hanover, Nelson, Northampton, Suffolk, Virginia Beach, and Westmoreland) in Virginia and primarily spanned across central and eastern Viginia. All samples were collected at the beginning of the production season (May–Jun 2025) between 1000 and 1200 HR.

Irrigation and collection of pondwater. Irrigation pondwater samples were collected as described by Park et al. (2020). High-density polyethylene (HDPE) bottles (0.5 L) were used to collect pondwater samples (n = 1 nursery^{-1}). Each HDPE bottle was thoroughly rinsed with pondwater three times before the final collection. All pondwater samples were collected close to the submersible intake pump at a depth of 0.6 m. After collection, samples were placed in a cooler with cold packs and then placed in a freezer set to −2 °C until samples were shipped for analysis.

Samples were sent to a commercial laboratory (Brookside Laboratories Amplify; New Bremen, OH, USA). Each sample was analyzed to determine calcium (Ca; ppm), hardness (ppm), iron (Fe; ppm), sodium (Na; ppm), and total suspended solids (TSS) (Brookside Laboratories Amplify). Pondwater pH and electrical conductivity (EC) were measured in-house with a portable probe (GroLine HI 9814; Hanna Instruments, Woonsocket, RI, USA). Alkalinity (ppm) was also measured in-house with a handheld colorimeter (HI775; Hannah Instruments). These specific parameters were chosen to represent common challenges that producers have with irrigation pondwater quality.

Soilless substrate collection. Samples of aged pine bark were collected from bark piles that the nurseries used to produce most of their crops. Sampling procedures were based on modified methods described by Kaderabek (2017); at each sampling location, sub-samples were collected by removing approximately 3 L of bark at different horizontal depths (0.3, 0.6, 0.9, and 1.2 m; n = 1) and at a constant vertical depth (1.5 m).

Received for publication 17 Sep 2025. Accepted for publication 14 Oct 2025.

Published online 11 Nov 2025.

[1]Hampton Roads Agricultural Research and Extension Center, VA Tech, 1444 Diamond Springs Road, Virginia Beach, VA 23455, USA

K.S.C. is the corresponding author. E-mail: kscriscione@vt.edu.

https://doi.org/10.21273/HORTTECH05773-25

Table 1. Irrigation pondwater quality of eight large nurseries within eastern Virginia.

Nursery	pH	EC	Alkalinity	TSS[i]	Hardness	Calcium	Iron	Sodium
		$mS\cdot cm^{-1}$	parts per million (ppm)					
1	7.9	0.23	50.0	80.0	111.5	35.6	<0.1	11.7
2	6.8	0.09	27.0	<1.0	28.4	5.4	<0.1	5.4
3	8.4	0.12	30.0	<1.0	28.8	8.4	<0.1	9.2
4	7.2	0.07	20.0	<1.0	12.3	3.6	<0.1	2.5
5	7.9	0.10	27.0	<1.0	28.8	6.7	<0.1	7.5
6	8.2	0.18	52.0	10.0	44.7	15.0	<0.1	7.5
7	8.7	0.30	87.0	50.0	70.7	17.4	<0.1	28.2
8[ii]	5.9	0.08	17.0	<1.0	18.6	5.5	<0.1	6.6
$\mu \pm SD$[iii]	7.6 ± 0.9	0.15 ± 0.1	38.8 ± 23.3	19.3 ± 35.1	43.0 ± 33.0	12.2 ± 10.6	–	9.8 ± 7.0
Rec. Std.[iv]	5.2–8.0	0.0–0.3	60.0–120.0	0.0–192.0	20.0–150.0	40.0–100.0	1.0–3.0	0.0–30.0

[i] Total suspended solids.
[ii] Water in the retention pondwater was pretreated with chlorine and filtration.
[iii] $\mu \pm SD$ = mean ± standard deviation.
[iv] Recommended standards by Robbins (2018) and Cabrera and Johnson (2015).
EC = electrical conductivity; TSS = total suspended solids.

This sampling method was used to best represent and mimic how producers sample their pine bark materials. Samples were stored indoors in sealed 4-mm polyethylene bags to minimize moisture loss in a 20 °C temperature-controlled room. Within 30 d, all samples were analyzed to determine substrate physical properties.

The North Carolina State University porometer method was used to characterize substrate physical properties (n = 3) (Fonteno and Harden 2010). Substate physical properties included the container capacity (CC; maximum water storage under gravitational drainage), AFP (minimum air space under gravitational drainage), total porosity (total pore space), and bulk density (dry mass per volume).

Statistical analysis. All means and standard deviations (*SD*s) were calculated using JMP Pro (18.0.0; SAS Institute, Inc., Cary, NC, USA).

Results and discussion

Irrigation. Irrigation pondwater from large nurseries in eastern Virginia generally exhibited suitable chemical properties for production, with most parameters within or near recommended ranges (Cabrera and Johnson 2015; Robbins 2018). While some values exceeded recommendations, results were comparable with irrigation water quality from other east coast specialty crop producers (Argo et al. 1997).

Irrigation water pH plays a critical role in determining the solubility and availability of mineral ions in the root zone (Peterson 1982). Recommended pondwater pH ranges between 5.2 and 8.0 (Cabrera and Johnson 2015). Pondwater pH among surveyed nurseries averaged 7.6 ± 0.9 ($\mu \pm SD$), with three nurseries exceeding 8.0 (Table 1). In principle, slightly alkaline pH levels are generally acceptable if alkalinity values are low (<60 ppm). Alkalinity indicates the capacity of water to resist changes in pH; therefore, low alkalinity can help manage high pH caused by low buffering capacity and rapid changes in pH (Lopez et al. 2010; Robbins 2018). However, alkalinity that is too low can result in inconsistent or declining pH values throughout production. Eastern Virginia nurseries generally exhibited low alkalinity (38.8 ± 23.3 ppm; recommended range, 60–120 ppm) (Cabrera and Johnson 2015) (Table 1), which highlighted that producers should be aware of potential challenges regarding maintaining pH levels or pH decline during cropping cycles. High alkalinity is a more common challenge among nurseries because high alkalinity resists acidification and can result in gradual increases in pH (Lopez et al. 2010).

Water hardness measures the combined concentration of Ca and magnesium (Mg) ions and can provide additional context for alkalinity (Lopez et al. 2010). Recommended hardness values range from 20.0 to 150.0 ppm, while recommended Ca values range from 40.0 to 100.0 ppm (Robbins 2018). Average nursery pondwater hardness (43.0 ± 33.0 ppm) and Ca (12.2 ± 10.6 ppm) were within or below these recommended ranges (Table 1). While low Ca may limit nutrient availability, high hardness or Ca can produce residues on foliage (Boser 2023), clog or damage irrigation equipment (Cabrera and Johnson, 2015), or result in nutritional imbalances in the root zone. These measurements indicated that treatment for hardness is not needed (Bilderback et al. 2017).

The EC serves as a common proxy for soluble salt concentrations in irrigation pondwater and is a critical parameter in managing ψ_S in the root zone. Because most container producers rely on controlled-release fertilizers, recommended irrigation pondwater EC is typically low (0.0–0.3 $mS\cdot cm^{-1}$) (Robbins 2018). Eastern Virginia nursery pondwater EC levels were within recommended levels (0.15 ± 0.1 $mS\cdot cm^{-1}$) (Table 1). Nursery retention ponds generally collect recycled surface runoff from applied irrigation, which can inflate pondwater EC values. High pondwater EC (>1.0 $mS\cdot cm^{-1}$) may require increased leaching fractions (volume of water leached ÷ volume of water applied) to prevent salt accumulation in the root zone (Owen et al. 2019); however, the measured values indicated that increased leaching fractions are not necessary.

The Na and chloride levels are common concerns for nursery producers because of the potential to induce imbalanced ψ_S and salt stress (Robbins 2018). Elevated Na levels can interfere with Ca, Mg, and potassium (K) uptake, modify K:Na ratios, and increase pH over time. However, sodium concentrations across surveyed

Table 2. Physical properties[i] of pine bark substrates used in outdoor container production for >1-gal. containers within nine Eastern Virginia nurseries.

Nursery	Container capacity		Air-filled porosity		Total porosity		Bulk Density	
	$cm^3 \cdot cm^{-3}$						$g \cdot cm^{-3}$	
1	0.59	0.02[ii]	0.34	0.04	0.92	0.03	0.18	0.01
2	0.36	0.02	0.37	0.01	0.73	0.01	0.17	0.00
3	0.35	0.03	0.38	0.03	0.73	0.03	0.16	0.01
4	0.42	0.03	0.33	0.07	0.74	0.05	0.21	0.01
5	0.42	0.02	0.42	0.04	0.84	0.06	0.17	0.01
6[iii]	0.55	0.01	0.22	0.03	0.77	0.02	0.19	0.01
7	0.45	0.01	0.46	0.03	0.91	0.03	0.16	0.01
8	0.44	0.03	0.41	0.05	0.85	0.02	0.16	0.01
9	0.52	0.04	0.28	0.06	0.79	0.02	0.17	0.00
μ ± *SD*[iv]	0.46 ± 0.08		0.36 ± 0.08		0.81 ± 0.08		0.18 ± 0.02	
Rec. Std.[v]	0.45–0.65		0.10–0.30		0.65–0.85		0.19–0.70	

[i] Measured during the North Carolina State University porometer analysis.
[ii] Standard deviation (n = 3).
[iii] Primarily used for 1-gal. containers.
[iv] μ ± *SD* = mean ± standard deviation.
[v] Recommended standards by Bilderback et al. (2013).

nurseries averaged 9.8 ± 7.0 ppm and were within the recommended ranges (0.0–30.0 ppm).

Additionally, Fe is an important micronutrient for plant development. However, high Fe levels can intensify the growth of Fe-born bacteria populations and result in unesthetic foliar deposits (Bilderback et al. 2017). Pondwater Fe levels were consistently low (<0.1 ppm) (Table 1) across surveyed nurseries and caused little concern (1.0–3.0 ppm) (Cabrera and Johnson 2015).

Irrigation pondwater can have high TSS from organic particulates, sediments, plant debris, or chemical precipitates from recirculated irrigation or surface runoff. High TSS can clog emitters or transport pathogens or residual agrochemicals (Abdi and Fernandez 2019). Average TSS values across surveyed nurseries were low (19.3 ± 35.1 ppm) and within recommended limits (0.0–192.0 ppm). Filtration is often recommended for producers to mitigate potential setbacks and is necessary when TSS is high (Fischer et al. 2018).

Soilless substrates. Large eastern Virginia nursery producers primarily source their pine bark substrates from North Carolina because of cost and local availability (Virginia nursery producers). The substrates physical properties measured in this case study are comparable to those reported by Altland et al. (2018), who surveyed physical properties of pine bark from commercial bark suppliers in North Carolina.

Eastern Virginia nursery substrates were, on average, within the recommended CC (0.46 ± 0.08 $cm^3 \cdot cm^{-3}$) and total porosity values (0.81 ± 0.08 $cm^3 \cdot cm^{-3}$); the recommendations for these range from 0.45 to 0.65 $cm^3 \cdot cm^{-3}$ and from 0.65 to 0.85 $cm^3 \cdot cm^{-3}$, respectively (Bilderback et al. 2013). Outdoor nursery producers in the eastern US will typically use substrates with lower water storage to mitigate waterlogged containers and maintain optimal physical properties during potentially long periods of high precipitation (Raviv et al. 2019).

Many large eastern Virginia nursery producers create a single unique substrate composite or use a pine bark-based substrate to produce most of their crops (Virginia nursery producers). The nurseries surveyed primarily use pine bark (stand-alone) without mineral sand (Virginia nursery producers). Pine bark used in nursery 1 contained the greatest CC (0.59 $cm^3 \cdot cm^{-3}$), and the producer typically incorporated two bark substrates (finer particles and coarser particles) from different sources (Virginia nursery producer). The finer particles likely settle within pores space and contribute to the increased CC (Table 1) (Bilderback et al. 2005). Bark substrates from nursery 6 also contained greater CC (0.55 $cm^3 \cdot cm^{-3}$); however, this is likely attributable to finer bark particles used for 1-gallon container production (Virginia nursery producer). Nursery 3 produced trees in larger containers (>15 gallons) and typically sourced coarser pine bark to increase drainage.

The substrates surveyed were slightly above the recommended AFP values (μ ± *SD*; 0.36 ± 0.08 $cm^3 \cdot cm^{-3}$); recommended values ranged from 0.10 to 0.30 $cm^3 \cdot cm^{-3}$ (Table 2). Altland et al. (2018) also reported average AFP values >0.30 $cm^3 \cdot cm^{-3}$ for aged pine bark from North Carolina suppliers. This assessment suggested that Virginia nursery producers may need to irrigate at greater volumes or frequently apply irrigation throughout a singular day to maintain suitable moisture conditions or avoid water-related stress (Mathers et al. 2007). Cyclic irrigation is an effective irrigation management technique that can help producers manage water availability and moisture distribution in bark-based substrates (Criscione et al. 2024).

Conclusion

A case study of nine large nurseries located in eastern Virginia was conducted to investigate whether producers maintained irrigation pondwater and substrate physical properties within recommended standards. The results of this case study showed that irrigation pondwater quality was generally within recommended standards. Pondwater alkalinity was, on average, low across nurseries and highlights that producers should be aware of potentially quick changes or inconsistent pondwater pH.

Pine bark substrates used by large nurseries located in eastern Virginia, on average, have suitable water storage values; however, average AFP values were slightly above recommended values. This highlights that nursery producers may need to irrigate with greater volumes or more frequently apply irrigation to avoid water-related stress.

References cited

Abdi DE, Fernandez RT. 2019. Reducing water and pesticide movement in nursery production. HortTechnology. 29(6):730–735. https://doi.org/10.21273/HORTTECH04298-19.

Altland JE, Owen JS, Jackson BE, Fields JS. 2018. Physical and hydraulic properties of commercial pine-bark substrate products used in production of containerized crops. HortScience. 53:1883–1890.

Argo WR, Biernbaum JA, Warncke DD. 1997. Geographical characterization of greenhouse irrigation water. HortTechnology. 7(1):49–55. https://doi.org/10.21273/HORTTECH.7.1.49.

Bilderback TE, Dole J, Sneed R. 2017. Water supply and water quality for nursery and greenhouse crops. NCCES. Raleigh, NC, USA. https://nurserycrops.ces.ncsu.edu/wp-content/uploads/2017/11/water-supply-and-water-quality-for-nursery-GH-crops-Bilderback-dole-sneed.pdf?fwd=no.

Bilderback TE, Warren SL, Owen JS Jr, Albano JP. 2005. Healthy substrates need physicals too!. HortTechnology. 15(4):747–751. https://doi.org/10.21273/HORTTECH.15.4.0747.

Bilderback T, Boyer C, Chappell M, Fain G, Fare D, Gilliam C, Jackson B, Lea-Cox J, LeBude A, Niemiera A, Owen J, Ruter J, Tilt K, Warren S, White S, Whitewell T, Wright R, Yeager T. 2013. Best management practices: Guide for producing nursery crops. Southern Nursery Assn., Acworth, GA, USA.

Boser S. 2023. A water quality toolkit for greenhouse and nursery production. Penn State Extension. University Park, PA, USA. https://extension.psu.edu/a-water-quality-toolkit-for-greenhouse-and-nursery-production.

Cabrera R, Johnson J. 2015. Evaluating water quality for ornamental plant production. Rutgers State University Cooperative Extension Fact Sheet FS893. Rutgers University Cooperative Extension, Blackwood, NJ, USA.

Criscione KS, Fields JS, Owen JS, Gentimis A. 2024. Stratified substrates enhance water storage and distribution between irrigation events. Soil Sci Soc Am J. 88(2):387–402. https://doi.org/10.1002/saj2.20636.

Fain GB, Gilliam CH, Tilt KM, Olive JW, Wallace B. 2000. Survey of best management practices in container production nurseries. J Environ Hortic. 18:142–144.

Fischer P, Raudales R, Mackay B. 2018. Learn how WaterQual, a new online tool, helps interpret your irrigation water quality testing. Nursery Management. June.

Fonteno WC, Harden CT. 2010. North Carolina State University Horticultural Substrates Lab Manual. North Carolina State University, Raleigh, NC, USA.

Fulcher A, LeBude AV, Owen JS, White SA, Beeson RC. 2016. The next ten years: Strategic vision of water resources for nursery producers. HortTechnology. 26(2):121–132. https://doi.org/10.21273/HORTTECH.26.2.121.

Kaderabek LE. 2017. Effects of aging on the physical, chemical, and hydrologic properties of pine bark substrates (Thesis). North Carolina State University, Raleigh, NC, USA.

Lopez R, Micklebart MV, Pasian C. 2010. Alkalinity management in soilless substrates. Purdue University Extension, West Lafayette, IN, USA.

Mathers H, Lowe S, Scagel C, Struve D, Case L. 2007. Abiotic factors influencing root growth of woody nursery plants in containers. HortTechnology. 17(2):151–162. https://doi.org/10.21273/HORTTECH.17.2.151.

Owen JS Jr, LeBude A, Fulcher A, Stanley J, Oki L. 2019. Leaching fraction: A tool to schedule irrigation for container-grown nursery crops. https://www.pubs.ext.vt.edu/SPES/SPES-128/SPES-128.html.

Park D, White SA, Hitchcock DR, Younts G. 2020. Collecting samples for agricultural irrigation water quality testing. Clemson University Extension, Chesterfield, SC, USA.

Peterson JC. 1982. Effects of pH upon nutrient availability in a commercial soilless root medium utilized for floral crop production. Ohio Agricultural Research and Development Center. https://kb.osu.edu/server/api/core/bitstreams/42b5bb05-fa54-5a7b-a666-1868bda80e87/content.

Raviv M, Leith JH, Bar-Tal A. 2019. Soilless culture theory and practice (2nd ed). Elsevier, San Diego, CA, USA.

Robbins JA. 2018. Irrigation water for greenhouse and nurseries. University of Arkansas Extension, Little Rock, AR, USA.

Stallknecht E, South K. 2025. Virginia horticulture production trends: 2017-2022. Virginia Cooperative Extension, Blacksburg, VA, USA.

US Department of Agriculture. 2023. 2022 Census of agriculture. https://www.nass.usda.gov/Publications/AgCensus/2022/Full_Report/Volume_1,_Chapter_1_US/.