Validation of Nursery and Greenhouse Best Management Practices through Scientific Evidence

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ADDITIONAL INDEX WORDS. BMPs, controlled-release fertilizer, cyclic irrigation, deficit irrigation, leaching fraction, vegetative zones, water management

SUMMARY. Nursery and greenhouse growers use a variety of practices known as best management practices (BMPs) to reduce sediment, nutrient, and water losses from production beds and to improve efficiency. Although these BMPs are almost universally recommended in guidance manuals, or required by regulation in limited instances, little information is available that links specific BMPs to the scientific literature that supports their use and quantifies their effectiveness. A previous survey identified the most widely used water management, runoff, and fertilizer-related BMPs by Virginia nursery and greenhouse operators. Applicable literature was reviewed herein and assessed for factors that influence the efficacy of selected BMPs and metrics of BMP effectiveness, such as reduced water use and fertilizers to reduce sediment, nitrogen (N), and phosphorus (P) loads in runoff. BMPs investigated included vegetative zones (VZs), irrigation management strategies, and controlled-release fertilizers (CRFs). Use of vegetative buffers decreased average runoff N 41%, P 67%, and total suspended solids 91%. Nitrogen, P, and sediment removal efficacy increased with vegetative buffer width. Changes in production practices increased water application efficiency >20% and decreased leachate or runoff volume >40%, reducing average N and P loss by 28% and 14%, respectively. By linking BMPs to scientific articles and reports, individual BMPs can be validated and are thus legitimized from the perspective of growers and environmental regulators. With current and impending water use and runoff regulations, validating the use and performance of these BMPs could lead to increased adoption, helping growers to receive credit for actions that have been or will be taken, thus minimizing water use, nutrient loss, and potential pollution from nursery and greenhouse production sites.

Nursery and greenhouse operators are concerned with the environmental impact of their production practices on irrigation water quality, improving it for reuse onsite and discharge, and the decrease in operational efficiency associated with resource losses (Mack et al., 2017). BMPs, as defined and used by the nursery industry, consist of a variety of specific measures or activities designed to reduce water and fertilizer use and to decrease fertilizer runoff and the eventual contamination of surface waters with agrichemicals (Bilderback et al., 2013). The purpose of implementing BMPs is to address water quality or water-management issues from specific sites or problems, increase plant production efficiency, and promote environmental stewardship. In contrast, a BMP used for the purposes of complying solely with the Clean Water Act is intended to address a specific environmental issue; these typically

do not necessarily have a positive impact on profitability, reducing the incentive for grower adoption.

Impairments to streams, lands, and rivers are caused by a variety of pollutants and are associated with a variety of activities, including agriculture. Eutrophication of lakes and estuaries is caused downstream of excessive sediment and nutrients discharges; reducing eutrophication is the main driver for BMP implementation in Virginia. Total maximum daily load limits (TMDLs) are regulatory agency-issued limitations of nutrient and sediment loads.

Implementation of nutrient and sediment TMDLs currently is taking place in several watersheds across the United States, including Florida, California, and the mid-Atlantic region. Perhaps the most prominent example of eutrophication in the United States is the Chesapeake Bay Watershed (CBW), which spans ≈166,000 km². The CBW is by far the largest watershed under TMDL restrictions and consists of large portions of Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia, and Washington, DC [U.S. Environmental Protection Agency (EPA), 2010]. The Chesapeake Bay TMDL has developed a multisector approach to implementation, identifying specific reduction goals to be achieved by each sector. These are essentially clean water goals intended to fully restore bay health by 2025. Agriculture is considered one of the leading sources of nonpoint source pollution to the CBW (EPA, 2010). Runoff exiting production sites is considered nonpoint source pollution by the EPA (2005). Although the reduction targets are jointly agreed on by stakeholders, state environmental agencies, and the EPA, the means of achieving them are left up to the individual states. As nonpoint sources of pollution, commercial nurseries currently are not regulated directly by TMDL guidelines, so changing grower practices typically will necessitate incentives to help attain the TMDL goals. Irrigation and nutrient runoff BMPs are among the most often prescribed tools that the nursery sector uses to meet clean water goals (Majsztrik and Lea-Cox, 2013); however, currently, the only recommended BMP for the CBW is runoff collection (EPA, 2010).

Due to the unique production aspects of container-grown crops, i.e., frequent irrigation and fertilization, managing water application and runoff both on and off site poses significant challenges. Irrigation of

Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
29.5735	fl oz.	mL	0.0338
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
2.5900	mile ²	km ²	0.3861

container-grown plants typically occurs on a daily basis when plants are actively growing due to the limited water-holding capacity of the soilless substrate (i.e., growing medium). Soilless substrates are chosen to optimize total air space (i.e., pore space), and especially macropores, to maximize aeration for root function and to minimize disease. Macropores reduce water retention and facilitate loss of water and agrichemicals from containers. Irrigation runoff from growing areas can contaminate on-site water storage or receiving surface water bodies. Adoption of BMPs can help growers maintain production efficiency while reducing resource use and preventing potential nutrient runoff from being discharged to protected waters (Bilderback et al., 2013).

Survey results show that growers are willing to proactively adopt BMPs to reduce environmental impacts (Fain et al., 2000; Garber et al., 2002; Mack, 2017), particularly if adoption also can be used as a tool for market differentiation. Nursery

BMP guides, including Bilderback et al., (2013), outlined BMPs that reduce or prevent nonpoint source pollution or waste from entering surface waters. However, although BMPs were identified and described, they were not specifically linked to refereed journal articles that supported their application, nor was the BMP effectiveness assessed. In the mid-Atlantic region alone, nursery and floriculture crop annual sales exceed \$1.42 billion (U.S. Department of Agriculture, 2012). There is a formidable challenge to growers in this relatively large industry, with a wide range of production practices, to select and implement BMPs that both increase production efficiency while simultaneously being recognized by the Clean Water Act for increasing environmental stewardship. Our objective was to validate the efficacy of selected Southern Nursery Association's *Best Management Practices Guide: Guide for Producing Nursery Crops* (Bilderback et al., 2013) to employ tail-water treatment technologies or reduce water use and fertilizer for subsequent reductions of sediment, N, and P loads in runoff.

Materials and methods

Mack et al. (2017) disseminated a 22-question survey to 357 Virginia nursery and greenhouse growers in-person or online. Sixty survey respondents identified the most frequently used irrigation-related BMPs for container-grown plants, including irrigation scheduling, optimized irrigation efficiency, plant need-based watering, and grouping plants by water needs. Although integrated pest management was also a frequently used BMP, irrigation-related practices are a driver of agrichemical losses from container-grown plants (Tyler et al., 1996b). The focus of the research featured in this paper is on the BMPs commonly used in Virginia that were identified by stakeholders: VZs, irrigation management, and CRFs. We conducted a literature search to identify BMP-supporting scientific literature. Refereed journal articles chosen for inclusion in our analysis were selected based on their relevance to the application of the BMP in reducing nutrients in runoff or irrigation water losses for container-grown plants.

Results and discussion

In this paper, for consistency, we will refer to each BMP by number as they are ascribed in the Southern Nursery Association's *Best Management Practices Guide: Guide for Producing Nursery Crops* (Bilderback et al., 2013).

Tail-water management

VZs/BUFFER ZONES [BMP #39 (BILDERBACK ET AL., 2013)]. VZs were identified by 76% of responding growers in Virginia (Mack et al., 2017) as a frequently used BMP for managing runoff at nursery production sites. VZs are defined as vegetated strips of land containing plants through which runoff from production areas is directed. A VZ can be as simple as a section of grass maintained alongside a production area. VZs mitigate sediment by increasing the surface area (i.e., foliage, roots, soil) exposed to runoff, decreasing runoff velocity, leading to deposition of sediment into the VZ and infiltration of runoff into underlying soils (Borin et al., 2005; Liu et al., 2008). Nutrient and sediment concentrations are reduced by being trapped in foliage/soil surface, taken up by plants, and infiltration of runoff into the soil [BMP #39 (Bilderback et al., 2013)]. VZs are similar in function to an urban stormwater BMPs known as vegetated filter strips or sheetflow to open space (Sample and Doumar, 2012).

Numerous studies, including Schmitt et al. (1999) and Helmers et al. (2005), have demonstrated that VZs are effective at filtering sediment from runoff (Table 1). In a VZ, heavier sediments tend to become trapped on the surface and finer sediment infiltrates with water (Liu et al., 2008). The efficacy of VZs for sediment removal ranged from 45% to 100% and varied with width and slope of the strip (Liu et al., 2008). Sediment removal varied from 68% with a 2-m-wide strip to 98% with a 15-m-wide strip (Abu-Zreig et al., 2004), respectively. The recommended width of a VZ for a nursery is suggested by regulatory guidance to be 15 m (Majsztrik et al., 2011). Zhang et al. (2010) found that enlarging the VZ width from 5 to 10 m improved sediment mitigation by 10% to 15%. A wider VZ (20 m) was found

Received for publication 4 Feb. 2019. Accepted for publication 7 May 2019.

Published online 5 August 2019.

Funded in part by the Virginia Nursery Landscape Association, Virginia Agricultural Council, Virginia Agricultural Experiment Station, and the Hatch Program of the National Institute of Food and Agriculture, U.S. Department of Agriculture, including work under award Specialty Crops Research Initiative project 2014-51181-22372 (Clean Water³).

This paper is based on information presented during the Clean Water³ program sessions, held as part of the American Society for Horticultural Science Annual Conference, 30 July to 3 Aug. 2018, in Washington, DC.

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<https://doi.org/10.21273/HORTTECH04303-19>

Table 1. Vegetative zone [Best Management Practice #38 (Bilderback et al., 2013)] effectiveness of nitrate (NO₃), nitrogen (N), phosphorus (P), and sediment mitigation as demonstrated in selected studies by vegetation type and plot slope.

Source	Vegetation type	Width (m) ^a	Mean plot slope (%)	Effectiveness by constituent (%)			
				NO ₃	N	P	Sediment ^a
Abu-Zreig et al., 2004	Red fescue (<i>Festuca rubra</i>)/birdsfoot trefoil (<i>Lotus corniculatus</i>) mix	2	2–3	—	—	—	68
	Varied	5	5	—	—	—	88
	Red fescue/birdsfoot trefoil mix	10	2–3	—	—	—	93
	Red fescue/birdsfoot trefoil mix	15	2–3	—	—	—	98
Gharabaghi et al., 2006	Perennial ryegrass (<i>Lolium perenne</i>), kentucky bluegrass (<i>Poa pretensis</i>)	5–15	—	—	—	—	>90% of larger aggregates removed in first 5 m
Li et al., 2016	Arrowhead (<i>Sagittaria trifolia</i>), ‘Kaohsiung’ rice (<i>Oryza sativa</i>), calamus (<i>Acorus calamus</i>)	Varied	—	—	95	93	95
Liu et al., 2008	Varied	10	9	—	—	—	45–100; optimal range for sediment trapping was 10 m wide at 9% slope
Patty et al., 1997	Perennial ryegrass	6	7	47	—	—	87
		12	7	69	—	—	100
		18	7	99	—	—	100
		6	12	85	—	—	99
		12	12	97	—	—	99
		18	12	100	—	—	99
		6	15	86	—	—	91
		12	15	95	—	—	97
		18	15	97	—	—	98
		7.5	—	—	26	52	63
Schmitt et al., 1999	Sorghum (<i>Sorghum bicolor</i>)	15	—	—	35	51	65
	25-year-old grass (unspecified)	7.5	—	—	35	71	89
	2-year-old grass (unspecified)	15	—	—	51	79	93
	2-year-old grass/shrub/tree (unspecified)	7.5	—	—	29	55	76
Syversen, 2005	2-year-old grass/shrub/tree (unspecified)	15	—	—	43	70	87
	Grass, aspen (<i>Populus</i> sp.), mountain ash (<i>Sorbus</i> sp.), birch (<i>Betula</i> sp.)	7.5	—	—	28	57	79
	Grasses (unspecified)	15	—	—	41	71	88
	Grasses (unspecified)	5–10	—	—	37–81	60–89	81–91
Uusi-Kamppa et al., 2000	Grasses (unspecified)	5	—	—	—	51–97	—
		10	—	—	—	38–96	—

^a1 m = 3.2808 ft.

particularly effective at removal of fine particles, since residence time (the average time the particles were in suspension) increased significantly (Liu et al., 2008). Geza et al. (2009) and Mayer et al. (2007) found that vegetative strips >50 m tended to be more consistent at sediment and N removal than narrower strips. However, wide strips are not always necessary for effective filtration. Gharabaghi et al. (2006) reported that more than 95% of larger sediment sizes in runoff were captured in the first 5 m of the VZ (Table 1).

VZs are also effective at reduction of nutrients in runoff water exiting production sites. Nitrate (NO₃) concentrations in runoff decreased by 24% to 48%, possibly due to dilution by rainfall, total N decreased by up to 95% (Li et al., 2016; Schmitt et al., 1999), and total P in runoff water decreased by 27% to 97% (Uusi-Kamppa et al., 2000). Furthermore, 82% of runoff volume can infiltrate a VZ, reducing nutrient content in runoff (Schmitt et al., 1999). The type of vegetation used in a VZ can impact the effectiveness of nutrient and sediment mitigation. Zhang et al. (2010) found that VZs consisting of trees had greater N and P removal efficacy than that of grass or combination vegetation VZs (grass and trees), whereas VZs composed of a single vegetation type were more effective at sediment removal (Table 1).

Vegetative zones are a cost-effective method for nutrient and sediment reduction (Majsztrik et al., 2011). Bohlen et al. (1914) found that cost and return on investments are the most important factors influencing how swiftly a farm practice, such as a BMP, is adopted. The “true-life” cycle cost of VZ implementation includes both establishment and maintenance (Geza et al., 2009). Zhou et al. (2009) compared three management practices: grassed waterways (grass-covered channels designed to filter water), grass VZs, and terraces and found that grass VZ implementation costs were lowest. Another cost incurred with the adoption of a BMP is the opportunity cost for the loss of potentially productive land that is instead used for the BMP. Placement of the VZ is important for cost effectiveness. Geza et al. (2009) found that using grassed waterways, or return ditches, was more cost

effective at reducing sediment load to receiving streams within a watershed. Smaller VZs spread out over a large area were more effective than larger strips located only in few select areas (Geza et al., 2009). Zhou et al. (2009) found that VZ establishment was about \$86/acre in year 2008 dollars, whereas annual maintenance was ≈5% of the establishment cost. Zhou et al. (2009) estimated VZ lifespan to be ≈10 years.

Irrigation management

The management of water (and the sediment and nutrients that it carries), is an essential and integral part of containerized plant production. Irrigation scheduling was cited as a BMP used by 89% of Virginia growers (survey respondents) (Mack et al., 2017). Due to the typical daily irrigation of container-grown plants tools such as irrigation management, BMPs may assist growers in optimizing their water use to address increasing regulatory pressure on water quantity and quality.

CYCLIC IRRIGATION [BMP #13 (BILDERBACK ET AL., 2013)]. Although a daily standard single-irrigation application can produce quality plants, it is not a viable practice for operations interested in limiting water use, and cyclic application is more water efficient (Morvant et al., 1998). Cyclic irrigation spreads daily water need of a plant over several daily applications (Bilderback et al. 2013). Cyclic irrigation applied to nursery production was noted by Whitesides (1989). Growers use cyclic irrigation to optimize crop irrigation through increased lateral flow, reduced preferential flow within the substrate, and replacement of water as used, thus improving water retention and potentially reducing the quantity of water used on a daily basis (Karam and Niemiera, 1994; Warren and Bilderback, 2005). Cyclic irrigation often can be implemented without making significant changes in irrigation equipment or setup (Fain et al., 1999). However, in other cases, growers may need to modify their existing irrigation infrastructure and possibly add an irrigation controller for scheduling and implementing multiple water applications. Cyclic irrigation can be applied by overhead sprinklers or microirrigation (spray stakes or drip irrigation).

Cyclic irrigation using overhead irrigation was found to increase water application efficiency (defined as the rate of application and retention by a container substrate) by 5% to 7% compared with the result from a single application (Karam et al., 1994). Spray stake irrigation resulted in more than a 10% increase in water application efficiency when multiple cycles were applied a day vs. a single application (Lamack and Niemiera, 1993). Tyler et al. (1996a) found an average 38% improvement in water application efficiency when comparing multiple vs. a single application using pressure compensated drip emitters to ‘Goldsturm’ orange coneflower (*Rudbeckia fulgida*) and ‘Skogholm’ bearberry cotoneaster (*Cotoneaster dammeri*). The increased water application efficiency associated with cyclic irrigation makes this practice particularly attractive for growers interested in optimizing water use.

Cyclic irrigation also has been demonstrated to reduce nutrient losses to container leachate to provide growers more control over crop nutrient use and to yield greater crop growth. In a comparison of cyclic with single-application irrigation, Tyler et al. (1996a) found that cyclic irrigation resulted in a reduced volume of effluent (18% less) and 50% less ammonium-N leached when compared with a single application. Karam et al. (1994) found that cyclic irrigation reduced N losses from containers by 43%, increased plant tissue N concentration 0.7% (on an absolute basis), resulting in 43% greater root dry weights compared with that of a single-application irrigation. Beeson and Keller (2003) found that cyclic irrigation applied using microspray heads increased southern magnolia (*Magnolia grandiflora*) height and increased trunk diameter over single application. Similarly, Fain et al. (1999) found that sawtooth oak (*Quercus acutissima*) growth (height and trunk diameter) was greater with cyclic irrigation than with single application. However, Tyler et al. (1996a) found that shoot and root growth of ‘Goldsturm’ orange coneflower was the same for cyclic and standard-irrigation methods, and irrigation type did not affect shoot and root N and P concentrations, suggesting that plant nutrient uptake was unaffected by the irrigation method.

Therefore, the beneficial effect on crop growth may be species or substrate dependent. A brief summary of collected studies demonstrating the effectiveness of cyclic irrigation in terms of nutrient use is provided in Table 2. Efficiencies varied from 4% to 38% depending on cyclic method and species.

PLANT NEED-BASED WATERING [BMP #14 (BILDERBACK ET AL., 2013)]. Plant water needs vary depending on factors such as seasonal and daily weather affecting evapotranspiration, container type and size, plant size, soilless substrate physical properties, growth rate, and species (Bilderback et al., 2013). Species-based differences in water needs are readily apparent to growers. For example, a drought-tolerant species such as indian hawthorn (*Rhaphiolepis indica*) may reach marketable quality when grown with up to a 80% water deficit (irrigating only after 80% of the plant available water is lost through evapotranspiration), whereas species such as sweet viburnum (*Viburnum odoratissimum*) and japanese privet (*Ligustrum japonicum*) are negatively affected by an 80% water deficit (Beeson, 2006).

In a study of container-grown woody ornamentals, including ‘Duncan’ slender deutzia (*Deutzia gracilis*), ‘Atrovirens’ giant arborvitae (*Thuja plicata*), ‘Albiflora’ japanese kerria (*Kerria japonica*), and ‘Ralph Senior’ arrowwood viburnum (*Viburnum dentatum*), irrigation was applied at 100% and 75% of daily water use (calculated by determining the volume of daily water loss from the substrate); treatments resulted in 66% and 79% less runoff volume than a control, respectively. The control received a single irrigation application of 19 mm·d⁻¹, which represented conventional irrigation. Plants were of similar or larger size than control (Warsaw and Fernandez, 2009). Less NO₃-N and phosphate-phosphorus (PO₄-P) were leached in the 100% and 75% treatments than occurred from the control and less water volume (38% and 59%, respectively) was applied when compared with the control. The BMP manual (Bilderback et al., 2013) contains a reference list of water requirements for many container-grown species that can be beneficial to growers for matching watering practices to individual

taxa or grouping taxa by water requirements.

Growers reported plant need-based watering as a BMP (Garber et al., 2002; Mack et al., 2017). Garber et al. (2002) surveyed Georgia growers and found that the frequency of growers that use need-based watering (17%) was equal to that of water recycling as a water conservation practice. Mack et al. (2017) found that plant needs-based watering was rated 8.3/10 on a Likert scale of use (least used = 0, most used = 10) among surveyed Virginia growers. A disadvantage of plant-need based watering is the potential need to alter operational practices for implementation by changing plant spacing, adding sensors (van Iersel et al., 2013), or modifying irrigation systems, all of which require, time, money, or both (Davies et al., 2016).

DEFICIT IRRIGATION [BMP #15 (BILDERBACK ET AL., 2013)]. Deficit irrigation, a practice to better manage water use, is accomplished by supplying a fraction of the estimated amount of water needed by the plant for growth. Practitioners implement deficit irrigation by limiting irrigation to a percentage of the water holding capacity of the substrate (Ahmed et al., 2014). In practice, deficit irrigation involves watering at low amounts, purposely applying less water than is needed to return the substrate to 100% of its effective container capacity, or targeting irrigation increases to be delivered only during drought-sensitive stages of growth. A brief review and summary of the most relevant plant deficit irrigation articles in terms of irrigation efficiency, crop response, and nutrient runoff mitigation as affected by species and irrigation application method are provided in Table 3. Growers may choose to modify their specific water application practices when using overhead irrigation to water deficit-irrigated plants instead of using drip irrigation (Davies et al., 2016). This permits growers who do not have specialized equipment such as sensors (van Iersel et al., 2013) to adopt deficit irrigation as a crop management practice.

Plant growth at particular stages can be affected by deficit irrigation. Alvarez et al. (2013) studied deficit-irrigated zonal geranium (*Pelargonium ×hortorum*), a herbaceous

ornamental, grown in a perlite, peat, and coconut fiber substrate maintained at 100% field capacity (irrigation water retained after containers are drained), 75% field capacity, and plants subjected to water stress at vegetative and flowering stages. Plants were shortest and had the least number of flowers when deficits were applied at the flowering stage (Alvarez et al., 2013). Therefore, plant quality is contingent on the stage of development when deficit irrigation is applied.

Davies et al. (2016) found that a value-added benefit of deficit irrigation was controlled growth in woody ornamentals. Welsh and Zajicek (1993) reported that plant growth was optimized at a 25% deficit (Table 3). However, a potential drawback of deficit irrigation is that it could lengthen the time to produce a crop. Beeson (2006) found that water restrictive irrigation regimes can reduce plant size, which can prolong production time, thus negating the water savings underpinning the use of the practice. However, Beeson (2006) noted drought-tolerant species can reach marketable status under water deficit-growing conditions. To maximize water application efficiency, the retention of substrate-applied water must be maximized (Warren and Bilderback, 2005). Lamack and Niemiera (1993) irrigated substrates that had a water deficit (relative to 100% moisture holding capacity) of 65% or 100%, or 400 or 600 mL, respectively. Regardless of whether irrigation was applied, continuously or intermittently, application efficiency was at least 11% greater for a substrate with a lower deficit [i.e., 400 mL (less dry)]. A relatively dry substrate can become hydrophobic, leading to preferential flow through the substrate and reduced irrigation efficiency. Bilderback and Lorscheider (1997) suggested wetting agents or surfactants as a BMP to prevent substrate hydrophobicity and increase substrate hydraulic conductivity and water retention.

All water use-reduction strategies must maintain commercially acceptable plant quality to be viable. Beeson (2006) compared a range of deficit irrigation amounts with a control irrigation application of 18 mm daily for indian hawthorn, sweet viburnum, and japanese ligustrum.

Table 2. Cyclic irrigation [Best Management Practice #13 (Bilderback et al., 2013)] effectiveness in water, leachate, nitrogen (N), and phosphorus (P) management as reported in reviewed articles, by species and substrate type.

Source	Species/substrate	Water applications (no.)	Crop response with cyclic irrigation	Water application efficiency	Leachate reduction vol	Proportion of constituent in leachate (%)	
						N	P
Beeson and Keller, 2003	'Symmes Select' magnolia (<i>Magnolia grandiflora</i>) /deep sand soil	Single, two, or three irrigations	Increased height and trunk diameter compared with single irrigation	—	—	—	—
Fain et al., 1999	sawtooth oak (<i>Quercus acutissima</i>)/pine bark 100%, and pine bark:coir 4:1	Single, three, or six irrigations	Growth (height and trunk diameter) greater than with single irrigation	Irrigation efficiency greater than with single irrigation	Leachate volume was reduced	—	—
Fare et al., 1994	'Compacta' japanese holly (<i>Ilex crenata</i>)/pine bark:peat 3:1	Single or three irrigations	Minimal effect on root growth	—	Leachate volume reduced 34% over single irrigation	N leached as nitrate (NO_3)-N decreased from 63% (single cycle) to 46% (three cycles)	—
Fare et al., 1996	Floss flower 'Blue Puffs' (<i>Ageratum houstonianum</i>)/pine bark:sand 6:1	Single or two irrigations with 30-min interval two irrigations with 2-h interval	Total root dry weight highest with two irrigations with 30-min interval; lowest with two irrigations with 2-h interval; total shoot dry weight lower with cyclic	—	Leachate volumes decreased 54%	47% less total N leached	—
Karam et al., 1994	'Apollo' aztec marigold (<i>Tagetes erecta</i>)/pine bark	Single or three irrigations with 1-h intervals between irrigations	43% greater root dry weights compared with single irrigation	4% increase with three irrigations	—	Reduced N losses from containers 43%	
Tyler et al., 1996a	'Goldsturm' orange coneflower (<i>Rudbeckia fulgida</i>) and 'Skogholm' bearberry cotoneaster (<i>Cotoneaster dammeri</i>)/pine bark:sand 8:1	Single, two three, or six irrigations	Growth unaffected by treatment	38% increase over single irrigation	—	Cyclic irrigation decreased total ammonium (NH_4)-N losses over single irrigation	Total P effluent loss unaffected by treatment

Table 3. Deficit irrigation efficacy [Best Management Practice #15 (Bilderback et al., 2013)] in nitrogen (N) and phosphorus (P) mitigation and water efficiency as demonstrated in selected studies by vegetation type and application.

Source	Species	Applications ^a	Crop response	Water efficiency	Runoff reduction vol	Proportion of constituent in leachate ^b	
						N	P
Ahmed et al., 2014	'Battle' ornamental pepper (<i>Capsicum annuum</i>)/1:1 sand, cotton stalk compost	100%, 85%, 70%, and 55% of water holding capacity	Reduced growth, yield, and vitamin C content of fruit with deficit irrigation	—	—	—	—
Alvarez et al., 2013	Zonal geranium (<i>Pelargonium xhortorum</i>)/6:3:1 sphagnum peat, perlite, coconut fiber	100% and 75% of water field capacity, and two deficit treatments- one during vegetative growth and one during floral development	Plants were shortest and had the least flowers when deficits were applied at flowering	—	—	—	—
Beeson, 2006	Indian hawthorn (<i>Raphiolepis indica</i>), sweet viburnum (<i>Viburnum odoratissimum</i>), japanese privet (<i>Ligustrum japonicum</i>)/64% pine bark, 24% sedge peat, 9% coarse sand (by vol)	18 mm·d ⁻¹ control and 20%, 40%, 60%, and 80% deficits of water available to plants	Drought-tolerant species such as indian hawthorn can retain marketability with up to 80% water deficits; deficit results in increased production time	—	—	—	—
Davies et al., 2016	Tatarian dogwood (<i>Cornus alba</i>), woodbine honeysuckle (<i>Lonicera perichlymenum</i>), border forsythia (<i>Forsythia xintermedia</i>)/pure peat and reduced peat (60% peat, 40% bark by vol)	Full or deficit irrigation, with deficits of 70%, 50% or 25% ET _A	Deficit irrigation- controlled growth using overhead irrigation; reduced peat substrate plants demonstrated less growth	Water use efficiency may be increased with deficit irrigation	—	—	—

(Continued on next page)

Table 3. (Continued) Deficit irrigation efficacy [Best Management Practice #15 (Bilderback et al., 2013)] in nitrogen (N) and phosphorus (P) mitigation and water efficiency as demonstrated in selected studies by vegetation type and application.

Source	Species	Applications ^a	Crop response	Water efficiency	Runoff reduction vol	Proportion of constituent in leachate ^a	
						N	P
Lamack and Niemiera, 1993	'Apollo' aztec marigold (<i>Tagetes erecta</i>)/pine bark	600-, 1200-, or 1800-mL deficits	—	Water application efficiency was 51% at 1200 mL medium moisture deficiency	—	—	—
Warsaw and Fernandez, 2009	'Duncan' slender deutzia (<i>Deutzia gracilis</i>), 'Albiflora' japanese kernia, 'Atrovirens' giant arborvitae (<i>Thuja plicata</i>), 'Ralph Senior' arrowwood viburnum (<i>Viburnum dentatum</i>)/85% pine bark 15% peatmoss	A 19-mm control, and irrigation replacing 100% daily water use, every other application with 100% daily water use alternating with 75% daily water use, and three application cycles: 100% daily water use, with two applications of 75% daily water use	Growth indexes of plants watered based on daily water use were equal to or greater than controls for all species	—	66% and 79% less operation runoff volume than control	100% and 75% daily water use irrigation volumes decreased quantities of nitrate-N by 38% and 59%. Concentrations were higher on some experiment days due to lack of water dilution	100% and 75% daily water use irrigation volumes decreased quantities of phosphate-P by 46% and 74% over the control. However, concentrations were greater on some experiment days due to lack of water dilution

^aET_A = actual evapotranspiration, 1 mm = 0.0394 inch, 1 mL = 0.0338 fl oz.

When qualitative evaluations for commercial acceptability were made by growers and compared with standard quality plants, growers rated deficit-irrigated plants more negatively than those grown using conventional irrigation methods. This example validates the concept that deficit irrigation should not be implemented without consideration of plant quality by the grower and or ultimately, the consumer. As studies estimate the species-specific deficit irrigation levels that maintain an acceptable quality, growers may begin to incorporate customized deficit irrigation regimes for their specific crops and climate. Decreased water application does reduce water and nutrient losses from containers (Davies et al., 2016) and production sites. Reducing water application amounts also reduces runoff volumes discharged from production sites (Fulcher and Fernandez, 2013b). Thus, deficit irrigation can help in meeting clean water goals.

LEACHING FRACTION (LF) MANAGEMENT [BMP #17 (BILDERBACK ET AL., 2013)]. LF is a unitless measure of the fraction of water that exits a container relative to the amount of water applied directly to the container (leachate volume following irrigation ÷ total volume of irrigation). For example, if 100 mL of water was applied to a container and 10 mL exited the container, then the LF is 0.10 (or 10% of the applied volume was leached). A summary of selected journal articles on LF management methods is provided in Table 4, these include crop response, water application efficiency, effluent reduction, and leachate nutrient concentration content.

A relatively high LF (>0.2) indicates that an excessive irrigation amount was applied (Bilderback et al., 2013). Nutrients and water are conserved through the use of low LF, such as those <0.1 (Fulcher and Fernandez, 2013a). Low LF may be used to increase water use efficiency [plant dry weight ÷ (volume irrigation water applied – volume irrigation water leached)]. If increased water use efficiency is coupled with decreased LF, nutrient leaching is reduced (Tyler et al., 1996b). Tyler et al. (1996b) compared spray stake-irrigated rooted cuttings of 'Skogholm' bearberry cotoneaster grown

Table 4. Leaching fraction (LF) [Best Management Practice #17 (Bilderback et al., 2013)] efficacy in nitrogen (N) and phosphorus (P) mitigation as demonstrated in selected studies by vegetation type and crop response.

Source	Species	LF*	Crop response	Irrigation efficiency	Effluent reduction vol (%)	Proportion of constituent in leachate	
						N	P
Ku and Hershey, 1992	'Yours Truly' zonal geranium	0, 0.1, 0.2, 0.4	Reduced growth with LFs of 0 and 0.1 compared with 0.2 and 0.4	—	—	—	—
Niemiera and Leda, 1993	—	0, 0.2, 0.4	Lower LF resulted in more plant available N	—	—	61% more total N leached at LF 0.4 than 0.2	—
Owen et al., 2008	'Skogholm' bearberry cotoneaster	0.1 or 0.2	Plant dry weight unaffected by low LF	—	64%	—	8% and 64% reduction in dissolved reactive P at LF 0.2 and 0.1
Tyler et al., 1996b	'Skogholm' bearberry cotoneaster	Low (0.0 to 0.2) vs. high (0.4 to 0.6) LFs	Reduced shoot and root growth by 10%	Irrigation use efficiency was 29% higher with low LF	44% and 63%	66% and 62% reductions in cumulative nitrate-N, ammonium-N	57% reduction in cumulative P with low LF

*LF = leachate volume following irrigation ÷ total volume of irrigation.

under low (0.0–0.2) vs. high (0.4–0.6) LFs and found that water use efficiency was 29% greater with those grown under the low LF. Low LF had a 44% lower irrigation volume, a 63% lower effluent volume, and 66%, 62%, and 57% reductions in cumulative $\text{NO}_3\text{-N}$, ammonium ($\text{NH}_4\text{-N}$), and P effluent contents compared with the high LF regimen (Tyler et al., 1996b). However, these increases in water and nutrient efficiencies reduced shoot and root growth by 10% (compared with greater LF), indicating that growers must balance the benefits of LF and subsequent increased efficiencies with the potential negative effects on plant growth (Tyler et al., 1996b). A similar result was found by Ku and Hershey (1992), who noted that growth of 'Yours Truly' zonal geranium was reduced under low LF (0.0 and 0.1), and that plants with LF of 0.2 and 0.4 had 37% greater shoot dry weight. Decreased growth associated with low LF may have been caused by soluble salt buildup in the substrate or water stress (Ku and Hershey, 1992). The LF that affects plant growth may be a matter of degree and species $\times$ environmental interaction, as Owen et al. (2008) found that reducing LF from 0.2 to 0.1 for 'Skogholm' bearberry cotoneaster containers decreased effluent volume 64%; however, plant dry weight was unaffected.

Niemiera and Leda (1993) conducted a column experiment with an irrigation regime of 5 d per week for 12 weeks to determine the effects of various LFs on N fate from CRFs. Bark with an LF of 0.4 had 61% more N leached than the bark with an LF of 0.2; substrate solution $\text{NO}_3\text{-N}$ concentrations were greater at low LF (0) than at high LF (0.4). Leaching fraction did not influence the CRF release rate, but lower LF resulted in more plant available N and less N losses through leaching. Furthermore, the effects of LF can be influenced by CRF placement in a container. Hoskins et al. (2014) found that fallow containers of pine bark-based substrate placed under low LF had lower nutrient effluent loads when CRF was applied via dibbled placement [CRF placed in a shallow hole (3-inch-deep, hand-formed) in the surface of the substrate and then backfilled] vs. incorporated placement throughout the substrate

within the container. The method of fertilizer application can therefore work in concert with the use of low LF to reduce nutrient leaching in containerized nursery production.

Growing plants at irrigation volumes that just meet plant daily water needs can result in low LFs and result in soluble salts accumulation in the container substrate (i.e., a relatively high EC value) that can be damaging to plants. Soilless substrate pore-water extractions to measure EC (a measure of soluble salt concentration) is a common method to assess the relative amount of mineral nutrients available to a plant (Fulcher and Fernandez, 2013a). Warsaw and Fernandez (2009) found that EC values of container-grown ‘Duncan’ slender deutzia, ‘Albiflora’ japanese kerria, ‘Atrovirens’ giant arborvitae, and ‘Ralph Senior’ arrowwood viburnum continually increased after being irrigated until the next irrigation event, and the authors’ attributed this finding to soluble salt accumulation. Therefore, growers using low LF to limit nutrient losses from leachate should monitor EC soon after irrigation to ensure soluble salts do not accumulate to toxic levels in the substrate, especially during periods of low precipitation (Fulcher and Fernandez, 2013a); this caution also was suggested when using the pour-through method as described by LeBude and Bilderback (2009). If soluble salt levels rise to a deleterious level, then LF may be increased to leach mineral nutrients or salts from the substrate. A disadvantage of LF as a tool to minimize nutrient loss is that larger containers may be more difficult to handle, and therefore more difficult to sample (Yeary et al., 2015). Stanley et al. (2003) devised a method to extract the substrate solution from large containers using a suction cup lysimeter, thereby decreasing the difficulty to monitor fertilizer adequacy from large containers (≥57 L).

Knowledge of container LF values throughout the growing season benefits growers by providing an understanding of how irrigation water application practices impact their fertilizer regime. Growers with high LFs can reduce water application and increase water- and nutrient-use efficiency. Nutrient runoff may be reduced by using low LF, making more

nutrients available for plant uptake for a longer period of time before being leached out of the container. A drawback of low LF is that growers may need to frequently monitor soluble salt levels to avoid reductions in plant growth due to salt buildup.

Nutrient management

CRFs [BMPs #97–#100 (BILDERBACK ET AL., 2013)]. CRFs are polymer- or resin-coated fertilizers that release nutrients gradually over weeks or months. CRFs have a high adoption rate in containerized woody ornamental production exceeding 80%; however, growers may supplement with fertigation (soluble fertilizer dispensed via the irrigation system) when the rate of mineral nutrient release from CRFs is inadequate to meet plant nutritional demand, or when CRFs are exhausted, for example at the end of the season, or when growers may be trying to push growth or replace nutrients after heavy rainfall events. CRFs are considered to be efficient because they release nutrients over an extended period of time, weeks or months, vs. soluble fertilizers, which are immediately available. In a review of mineral nutrition literature, there was a 19% to 89% reduction in N leaching of greenhouse nursery crops when using a resin- or polymer-coated CRF compared with water-soluble fertilizer or sulfur-coated urea (Chen and Wei, 2018). In addition, CRFs reduce the potential for fertilizer salt buildup in the substrate and need for excessive mineral nutrient leaching (Broschat, 1995, Rathier and Frink, 1989). Therefore, CRFs can reduce the potential of discharge of nutrients to surface waters by decreasing the effluent nutrient load coming from container plant production sites (Broschat, 1995; Godoy and Cole, 2000). A summary of selected journal articles that illustrate the impact of CRF application on crop species and growth response, as well as nutrient retention and leaching (N and P), is provided in Table 5.

In two studies, the most commonly found N form in leachate (73%–85% of total N leached) was NO₃-N (Cox, 1993; Million et al., 2007), a mobile nutrient that readily leaches in soilless substrates. Nutrient losses through leachate and runoff

reduce nutrient availability to plants, reduce grower profit, and may contaminate surface water. Depending on application method and crop production practices, NO₃ in nearby water may exceed concentrations permitted by drinking water standards (Yeager et al., 1993), contribute to nutrient loads in impaired waterways, and potentially promote algal blooms and anoxic conditions. Application of fertilizer through fertigation can be inefficient if delivered through overhead irrigation since nutrient-laden water falls in between containers (Sammons, 2008). Shoot dry weight has been found to be equal to or lower for plants grown with CRF vs. liquid fertilizer depending on CRF longevity (Broschat, 1995; Cox, 1993). In similar studies, the use of CRFs have been consistently reported to reduce nutrients loss to leaching (Mikkelsen et al., 1994; Oertli, 1980; Yeager et al., 1993) and to reduce fertilizer cost when compared with liquid fertilization. In addition to these benefits, Wright and Niemiera (1987) reported container-grown woody nursery crops grown using CRFs have had equivalent or enhanced growth compared with those grown using liquid fertilizers. Some growers may choose to use a combination of CRF and liquid feed. However, the combination of constant liquid feed and CRF produced rosemary (*Rosmarinus officinalis*) plants with reduced shoot weight and plant height (Boyle et al., 1991) compared with either liquid feed or CRF exclusively. Boyle et al. (1991) hypothesized that the combination treatment may have suppressed plant height due to increased salinity or a nutrient imbalance.

CRF-application practices, such as time of application and placement, can affect fertilizer efficiency. Some growers incorporate CRFs into the substrate or apply CRFs as a top-dress (i.e., placed on substrate surface) at the time of planting or potting (Majsztrik et al., 2011). Early N losses when 2- to 3-month or 70-d CRFs were applied in a single application were equal to or exceeded those from the use of soluble fertilizer applied via irrigation at the same annual rate, depending on the irrigation method employed (Cox, 1993; Table 5). Cox (1993) found that N losses were greatest in the first 30 d or half of

Table 5. Controlled-release fertilizer (CRF) [Best Management Practice #97 to #100 (Bilderback et al., 2013)] efficacy in nitrogen (N) and phosphorus (P) mitigation as demonstrated in selected studies by vegetation type and crop response.

Source	Species	Applications	Crop response	Runoff	Proportion of constituent in leachate	
					N	P
Broschat, 1995	'Mauna Loa Supreme' peace lily (<i>Spathiphyllum</i>), areca palm (<i>Chrysalidocarpus lutescens</i>)	Liquid, granular, and CRF	Shoot dry weight equal to or lower for CRF vs. liquid fertilizer (soluble fertilizers applied in irrigation water)	—	Nitrate (NO_3) leaching reduced over time	Between 11% and 28% of phosphate (PO_4)-P applied was leached from all fertilizer treatments
Broschat, 2005	None	CRF: 8–9 mo. Osmocote 15N–3.9P–10K (ICL Specialty Fertilizers, Summerville, SC) and Nutricote 18N–2.6P–6.7K (type 180) (Chisso-Asahi, Tokyo, Japan)	—	—	Osmocote kept 8% NO_3 -N and 11% ammonium (NH_4 -N); Nutricote kept 21% NO_3 -N and 28% NH_4 -N	Osmocote and Nutricote kept 46% and 65.2% of P content after 7 mo.
Cox, 1993	'First Lady' aztec marigold (<i>Tagetes erecta</i>)	Two CRFs and one water-soluble fertilizer	Average shoot dry weight was 8.9% lower with CRF treated plants	Leachate volume was 12.5% greater with CRF-treated plants	N losses were greatest in first 30 d after CRF application; >1/2 the total N [mostly nitrate (NO_3)-N] leached was collected during this time	—
Godoy and Cole, 2000	'Howard's Silver' nippon spirea (<i>Spiraea nipponica</i>)	CRF, triple superphosphate alone, and CRF plus triple superphosphate	CRF plus triple superphosphate treated plants had larger root dry weights than the other two treatments	—	—	Large proportion of P from triple superphosphate treatments leached in small leachate volume; CRF plus superphosphate treatment leached P consistently; CRF leached P after a lag time of little initial leaching

(Continued on next page)

Table 5. (Continued) Controlled-release fertilizer (CRF) [Best Management Practice #97 to #100 (Bilderback et al., 2013)] efficacy in in nitrogen (N) and phosphorus (P) mitigation as demonstrated in selected studies by vegetation type and crop response.

Source	Species	Applications	Crop response	Runoff	Proportion of constituent in leachate	
					N	P
Hershey and Paul, 1982	'Bright Golden Anne' garden chrysanthemum (<i>Chrysanthemum × morifolium</i>)	Three rates each of CRFs and liquid feed fertilizers	No significant differences in fresh weight but delay in flowering with CRF treatments	LF ² was about 27% for both fertilizer types	CRF leaching losses leveled off after 5 weeks, whereas liquid feed leaching losses continued to increase; amount of N leached with CRF was about one-half of liquid feed using the same N application; liquid feed N leaching losses were four times greater than CRF	—
Million et al., 2007	Sweet viburnum (<i>Viburnum odoratissimum</i>)	CRF: Osmocote 18N-2.6P-10K (8-9 mo.)	Surface applied fertilizer did not impact growth	Surface applied fertilizer cut losses of nutrients through leaching	NO ₃ -N was most common form of N found in leachate; N leaching losses were 11% to 18%	P leaching losses were 7% to 13%
Rathier and Frink, 1989	'Plumosa Compacta' Youngstown' creeping juniper (<i>Juniperus horizontalis</i>), 'Conica' white spruce (<i>Picea glauca</i>)	CRF or soluble N sources; trickle or overhead irrigation	Juniper shoot growth was comparable across fertilizer treatments	—	36% more leaching of NO ₃ -N than with drip irrigation when overhead irrigation was used	—

²Leaching fraction (LF) = leachate volume following irrigation ÷ total volume of irrigation applied.

duration after CRF application and that more than 50% of the total N (mostly NO₃-N) leached was collected during this time. These data support the concept that NO₃-N losses (greater leachate concentrations) are more likely to occur when CRF is applied in one large dose to the potting medium than when it is top-dressed in two half-rate applications during the growing season (Cox, 1993; Rathier and Frink, 1989) using short-duration CRFs. The early season spike in NO₃-N loss was attributed to release of fertilizer at concentrations above that which could be readily used by plants. Less N was recovered in leachate when 2- to 3-month or 70-d CRFs were top-dressed or surface applied, rather than incorporated, at the same rate (Cox, 1993). This may be attributed to intermittent drying on the substrate surface that may reduce the rate of nutrient release from CRFs (Broschat, 2005; Lunt and Oertli, 1962; Oertli and Lunt, 1962).

In a study of mineral nutrient leaching in container-grown tropical foliage plants, Broschat (1995) found that leaching was greatest for soluble granules and lowest for a 3- to 4-month CRF surface applied every 2 months, or a 12- to 14-month CRF applied once. Between 11% and 28% of applied PO₄-P was leached from all fertilizer treatments. During the 6-month experiment, PO₄-P leaching generally increased, then decreased after week 22, and leachate PO₄-P was greater for plants grown with liquid fertilizer or soluble granules than for those grown with CRFs. The PO₄-P leaching curve demonstrated that the magnitude of nutrient leaching was correlated with the timing of storm events.

Additional cultural practices that affect mineral nutrient losses can include the incorporation of substrate amendments. Some growers amend substrate with superphosphate before planting, and due to the high organic matter content and saturated hydraulic conductivity of soilless substrate, there is increased leaching of P as compared with a similarly amended mineral soil (Yeager and Ingram, 1985). Another cultural practice that may benefit growers is the use of drip or microirrigation, which can work in tandem with CRFs to conserve water (Bilderback, 2002), and therefore

reduce the potential for nutrient leaching from containers. Containerized crops frequently are planted in porous substrates and are irrigated daily, potentially leading to increased nutrient losses, particularly with overhead irrigation. Rathier and Frink (1989) found that 36% more $\text{NO}_3\text{-N}$ leached with overhead irrigation compared with drip.

CRF can reduce N and P losses, but implementation of appropriate cultural practices also can maximize these benefits. Practices that support the reduction of nutrient losses include the 1) use of CRFs of optimal duration that best mimic plant growth rate throughout production, or 2) multiple CRF applications (i.e., top-dressed) with a release duration shorter than the production cycle rather than large single dose incorporation (pre-plant mixed into substrate), and 3) the use of micro-irrigation. When a short-term CRF was used in multiple applications during a production cycle and compared with a single application of a long-term CRF at the same rate, the short-term fertilizer resulted in the least (34% less) $\text{PO}_4\text{-P}$ lost to leachate (Broschat, 1995). New, long-term CRFs have improved nutrient release rates as compared with older CRF formulations. However, irrigation management during the first half of the growing season, when CRF nutrient losses are at their peak (due to nutrients applied exceeding those taken up by the crop) (Hershey and Paul, 1982), can reduce nutrient losses. Cultural practices, combined with the use of CRFs, can help growers to mitigate nutrient losses while reducing N and P in container

leachate and runoff from growing operations.

A drawback to CRFs is that crops with comparatively short production cycles may be finished before CRFs can fully release, and therefore CRFs are better suited to crops with longer production cycles. However, when CRFs do not fully release during production, consumers can benefit from the remaining fertilizer released by CRFs (England et al., 2012). Application of CRFs also can be labor intensive, particularly if manually applied to the surface. For containers that are prone to tip over and treated with surface-applied CRFs, fertilizer spillage, waste, and pollution are a distinct disadvantage. CRFs are typically more expensive than liquid feed, but less management is usually needed to grow crops with CRFs (England et al., 2012). With the use of long-term CRF formulations, growers may find that the potential drawbacks of CRFs use are less problematic.

Conclusions

We linked the most cited and most frequently used water-related BMPs that were identified in a previous survey of Virginia ornamental growers with the scientific literature that supported their use. Although the data were obtained from Virginia sources, we believe our findings and conclusions to be broadly applicable to the mid-Atlantic and southern regions of the United States since growing conditions and practices are similar throughout. Growers face increasing regulatory pressure to produce plants using less water and generating less runoff and N, P, and sediment loading. BMPs help

growers to meet these demands, permitting growers to contribute to environmental restoration of receiving waters. Growers are cognizant of environmental concerns and readily adopt BMPs that reduce water use and reduce fertilizer losses from their production areas (Mack et al., 2017). Specific BMPs may be chosen and adopted by a grower or tailored to the specific needs of the nursery operation. Irrigation decisions are largely based on grower experience in working with specific plants and their water needs for optimal growth. The individual taxa growing requirements, climate conditions, and grower preferences in crop production, such as substrate and fertilizer type, highlight the complexity of production decisions for achieving optimal plant quality and marketability. These factors underscore the necessity to avoid a one-size-fits-all approach to water and nutrient management and point toward the flexibility offered by a menu of water and nutrient management BMP tools for growers to meet production goals while reducing adverse impacts on protected waters. The efficacy of these BMPs are summarized in Table 6. In linking the relevant scientific evidence to specific BMPs, we provide growers and regulators support and confidence in using BMPs for ornamental horticulture water management. Such support validates and legitimizes current recommended BMPs for the nursery industry.

We discovered a wide range of experimental approaches to documenting the results of irrigation and fertilizer treatments in the literature. This experimental diversity is witnessed by the

Table 6. Summary of average [various Best Management Practices (BMP) (Bilderback et al., 2013)] efficacy in methods to increase water efficiency, decrease leaching or runoff, and subsequent reduction in nitrate (NO_3), nitrogen (N), phosphorus (P), and sediment.

BMP no.	Method description	Qualifier ^a	Increase in water application efficiency (%)	Leachate or runoff reduction vol (%)	Avg effectiveness by constituent (%)			
					NO_3	N	P	Sediment
13	Cyclic irrigation	Two to six irrigations	21	44	—	36	—	—
15	Deficit irrigation	20% to 80% deficit	51	73	—	49	60	—
17	Leaching fraction	0.1 to 0.6 leaching fraction	29	59	—	57	11	—
38	Vegetative buffer/strip	<15 m wide	—	—	80	35	62	86
		≥15 m wide	—	—	99	43	68	91
97–100	Controlled-release fertilizer	Compared with water-soluble fertilizer	—	—	—	55	34	—

^a1 m = 3.2808 ft.

gaps in the comparisons of journal article's impact data featured in the tables. Increasing uniformity across scientific papers for BMP research will permit more detailed comparisons, such as meta-analysis, of scientific data-supporting horticultural practices. Future research should focus on linking the additional relevant scientific evidence to other widely used BMPs to further provide growers solid support and confidence in using BMPs for ornamental horticulture water and fertilizer management.

In summary, we have linked water-related BMPs to specific peer-reviewed journal articles. This linkage 1) documents the scientific validity of the BMPs, 2) gives growers the confidence that BMPs are valid measures to ensure positive environmental impacts as well as being profitable measures, and 3) provides regulatory agencies with the substantiation that BMPs are in fact conserving water resources and minimizing nutrient inputs into ground and surface waters.

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