Best Management Practice Use and Efficacy for the Virginia Nursery and Greenhouse Industry

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ABSTRACT

Best management practices (BMPs) are used in the nursery and greenhouse industry to reduce water and nutrient waste while optimizing production efficiency. These practices serve to help meet clean water standards to limit contaminants entering impaired waters such as the Chesapeake Bay estuary. However, research is lacking on which BMPs are most widely used or are the most efficacious for Virginia nursery and greenhouse growers. The objectives of this research were to assess BMP use, identify barriers to adoption, and assess their efficacy.

We conducted a survey of Virginia growers to assess the 1) most widely used BMPs, 2) rationale for BMP use, and 3) barriers to BMP adoption. Sixty growers (17%) that were invited responded to the survey. The most widely used BMPs included irrigation scheduling, integrated pest management (IPM), optimized irrigation efficiency, plant need based watering, grouping plants by water needs, use of controlled-release fertilizers (CRFs), and on-site water capture and collection. The most frequently cited reasons for grower use of BMPs for fertilizer, water, and sediment management were monetary savings, water or resource savings, and environmental stewardship. Environmental stewardship was a frequently selected reason for BMP use across all categories. Cost was the most frequently selected barrier to BMP adoption. We identified and cited the scientific literature which assessed the effectiveness of most widely used BMPs (vegetative zones, irrigation BMPs, and CRFs). Linking the science supporting BMP use to the widely used BMPs gives growers confidence in implementing production practices that limit water contamination, prevent waste, and help to limit discharges of nutrients and sediment and thus contribute to environmental restoration of receiving waters.

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ABSTRACT (Public)

Best management practices (BMPs) are used in the nursery and greenhouse industry to increase production efficiency, and also serve to help meet clean water limitations on contaminants entering waters such as the Chesapeake Bay Watershed. Research is lacking on which BMPs are most widely used or most efficacious for Virginia nursery and greenhouse growers. Objectives of this work were to determine BMP use, barriers to adoption, and scientific efficacy.

We conducted a survey of Virginia growers to find the 1) most widely used BMPs, 2) reasons behind BMP use, and 3) any barriers to BMP adoption. Sixty growers (17%) responded to the survey. The most widely used BMPs included irrigation scheduling, integrated pest management, optimized irrigation efficiency, plant need based watering, grouping plants by water needs, on-site water capture and collection, and use of controlled-release fertilizers (CRFs). Cost was a barrier to BMP adoption, and environmental concern was a commonly reported reason for BMP use. We documented the science supporting selected water-related BMPs (grass buffer strips, CRFs, and irrigation optimization BMPs). Providing the science supporting BMP use gives growers confidence in implementing BMPs to limit water contamination, and prevent waste.

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Literature review

Virginia's ornamental horticulture industry

Runoff from ornamental crop production is considered nonpoint source pollution by the U.S, Environmental Protection Agency (USEPA), and agriculture is considered to be a leading contributor of nonpoint source pollution entering the Chesapeake Bay Watershed (CBW) (U.S. EPA, 2005). To address this issue, the USEPA has imposed a Total Maximum Daily Load (TMDL), which limits the discharge of nitrogen (N), phosphorus (P), and sediment to the Bay (U.S. EPA, 2010, 2015). Based upon the TMDL and its implementation plan (Commonwealth of Virginia, 2010, 2012), the Commonwealth of Virginia must reduce the loadings resulting from the TMDL within the CBW or risk unspecified federal action. Nurseries and greenhouses are expected to collect and reuse runoff and leachate by 2025 to help meet the TMDL (Commonwealth of Virginia, 2010). Implementing best management practices (BMPs) may be used to meet the TMDL reductions, also known as the clean water goals (Majsztrik and Lea-Cox, 2013). Best management practices appear in the *Best Management Practice Guide: Guide for Producing Nursery Crops* (Bilderback et al., 2013), and are measures or schedules of practices useful for preventing nutrient and sediment runoff from ornamental production sites from entering into impaired waterways. The exact definition of a BMP as it appears in the BMP manual is (Bilderback et al., 2013):

“[S]schedules of activities, prohibitions, maintenance procedures, and structural or other management practices found to be the most effective and practicable to prevent or reduce the discharge of pollutants into the air or waters of the United States.”

The Clean Water Act (CWA) (CWA, 1972) did not specifically define the term BMP, but rather, referred to the use of BMPs defined under the USEPA National Pollutant Discharge Elimination System wastewater permitting, conditions of which are under Title 40 of the Code of Federal Regulations (CFR) §122.44. This permitting program was authorized by section 402 of the CWA. Section 404 of the CWA exempts agriculture from its permitting requirements. Agriculture has agreed to voluntarily meet the TMDL reductions. It was upon the EPA’s BMP definition that the BMP manual’s definition was based (NPDES, 2016, 40 CFR §122.2):

“Best management practices (“BMPs”) means schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of “waters of the United States.” BMPs also include treatment requirements, operation procedures, and practices to control plant site runoff, sludge or waste disposal, or drainage from raw material storage.”

The ornamental industry’s BMP definition is similar to that used by USEPA, and for good reason. If the ornamental industry adopts a BMP definition that significantly differs from EPA’s definition, the BMPs in the manual will not be viewed by USEPA as practices that can be employed to reduce runoff of plant production-related contaminants into surface waters.

Significant deviation from EPA's definition could result in the EPA's failure to recognize the value of the BMPs in the BMP manual.

Importance of best management practice study

The focus of this project was the assessment of BMP use in Virginia's ornamental horticulture industry, and to provide specifically targeted information for the Virginia's nursery and greenhouse crop growers. The use of individual BMPs has been studied in recent years; however, few studies have analyzed BMP effectiveness in ornamental horticulture or specifically assessed BMP use by the industry. BMPs are likely to affect production; sometimes positively, but they can negatively impact it as well (although growers are unlikely to adopt them if this is the case). Virginia's ornamental horticulture industry has accounted for over $213 M in annual cash receipts, and contributes to the Mid-Atlantic region's annual nursery and greenhouse sales of over

$1.4 B (NASS, 2012). Thus, impacts on production and potential costs of each BMP should be assessed in tandem with impacts on water use and quality. This context helps to guide an analysis of BMP use and effectiveness for Virginia's ornamental horticulture industry.

Best management practices addressed in the literature

Individual state examples. Although the use of BMPs has increased in popularity over the last few decades, few studies have been conducted on BMP implementation. Of these studies, several provide information applicable to an analysis of Virginia's BMP use and effectiveness. Fain et al. (2000) surveyed twenty-four nurseries in Alabama regarding the use of multiple BMPs. All growers used multiple BMPs. Popular BMPs included water management related BMPs, such as collection ponds and cyclic irrigation, controlled-release fertilizers, horticultural oils, the use of water management personnel, filter or vegetative zones, spacing herbicide applications, and pest scouting (Fain et al., 2000). Fain et al. (2000) found that Alabama growers were concerned with environmental impacts and were willing to be proactive in making changes in operation production practices. Consumers may support this proactive view. Consumers are interested in sustainable products, and growers support implementation of sustainability practices, but growers feel that these practices must be compatible with existing production systems for ease of adoption (Dennis et al., 2010).

Yeager et al. (2010) studied BMPs in Florida nursery operations. The challenge facing the nursery industry is maintaining profits while also using production practices which engender environmental protection (Yeager et al., 2010). Growers are therefore charged with implementing management practices that are economically, technologically, and environmentally feasible. Best management practices are tools by which growers may meet these challenges while maintaining profitable production practices. Some benefits of implementing BMPs include (Yeager et al., 2010):

1. Protection from the need for increased regulatory scrutiny.
2. Minimization of movement of surface water contaminants, such as nutrients, through runoff.
3. Better production efficiency and cost effectiveness.
4. Demonstrate voluntary willingness to take action and show cognition of ornamental horticulture environmental challenges, preempting the need for mandatory regulatory intervention in some situations.

5. Alleviate negative views regarding grower contribution to agricultural nonpoint source pollution, thus preserving ornamental horticulture's reputation.

Schoene et al. (2006) found that the most widely used water management BMPs in Florida container nurseries with overhead or microirrigation systems included: 1) grouping plant species by irrigation needs (adopted by 74% of nurseries), 2) grouping container sizes by water needs (69% of nurseries), 3) ensuring proper irrigation application pressure (45% of nurseries), 4) collecting operation runoff (34% of nurseries), and 5) monitoring water application amounts (34% of nurseries). The purpose of irrigation is to supply sufficient water resources to support normal growth (Yeager et al., 2010) without unnecessary waste. Yeager et al. (2010) found that the main factors that Florida nursery operators used in irrigation frequency included: 1) plant observation (74% of responding nurseries), and 2) the utilization of a fixed irrigation schedule (59% of responding nurseries). Irrigation application is an important area in which to implement BMPs because overhead irrigation can have low application efficiency (Yeager et al., 2010). Less frequently used BMPs include monitoring container nutrient levels, monitoring substrate moisture via sensors, and annually verifying irrigation uniformity (Yeager et al., 2010).

BMPs protect water resources from the detrimental effects of environmental contaminants that may potentially result from cultural practices (Bilderback, 2002). BMP use varies from site to site, and may be modified depending upon the needs of the production operation; therefore, not all BMPs are necessary, applicable, or beneficial at a single operation site (Bilderback, 2002). Bilderback (2002) found that because most of the containers up to 5 gallons are watered via overhead sprinkler systems, improving overhead sprinkler irrigation efficiency is important.

Irrigation system design has the greatest impact on overhead system efficiency, and a defective design may have up to a 300% variability in water application efficiency, or irrigation effectiveness at applying and retaining water in the container substrate (Fare et al., 1994; Majsztrik and Lea-Cox, 2013, Bilderback, 2002, Furuta, 1978). Irrigation water may fall between containers, causing irrigation runoff; microirrigation systems may be used to provide greater efficiency in conveying water and nutrients to nursery crops compared to overhead application (Bilderback, 2002). Cyclic irrigation improves irrigation efficiency (38%) and can be used to improve nutrient efficiency (Tyler et al., 1996). Bilderback (2002) recommends grouping plants by substrate, container size, and plant species irrigation needs, and using isolation valves atop risers to help prevent water waste or limit portions of an irrigation zone once a crop has been removed.

Nurseries and greenhouse operations are encouraged to capture, contain, and recycle runoff, with the goal of retaining the applied irrigation water on the operation's property (Bilderback, 2002; Bilderback et al., 2013). Bilderback (2002) concluded that BMPs related to runoff handling had the most impact in reducing negative environmental effects, and that riparian vegetative zones were the most effective BMPs for protecting water quality in the state of North Carolina.

Multi-state management practices. Yeager et al. (1993) studied container runoff in six states, including Virginia. While each state's information was not presented separately, analysis of the results may be of interest to Virginia's ornamental horticulture industry. States surveyed included Virginia, Ohio, Alabama, Florida, North Carolina, and New Jersey. The study focused largely on nutrient runoff for container nurseries, a major concern for states tributary to the

Chesapeake Bay, including Virginia. Yeager et al. (1993) noted that there is a growing public perception that agriculture contaminates water, and that more study is needed to determine the extent of agriculture's effect on the environment. BMPs help to reduce potentially negative environmental impacts from agricultural activities. Citing the potentially polluting effects of nutrient runoff from fertilizer application, Yeager et al. (1993) stressed the need for implementation of BMPs to help decrease runoff nutrient levels that may be in excess of federal drinking water standards. Suggested management practices to consider included (Yeager et al., 1993):

1. Nutrient level monitoring in runoff, well water, collection water, and water discharged from the property.
2. Changing controlled-release fertilizer type if necessary to reduce early season spikes in nutrient runoff.
3. Keeping equipment, such as fertilizer spreaders, properly calibrated.
4. Monitor irrigation duration as needed.
5. Improve irrigation system efficiency when feasible.
6. Use grass strips along surface waterways for water filtering purposes.
7. Consider using several connected reservoirs to promote biological degradation.
8. Take measures to prevent or contain spillage from tanks containing concentrated fertilizer solutions, in accordance with applicable regulations.
9. Build up borders to prevent water flow onto or from property.

The ornamental horticulture industry faces the challenge of approaching production practices in light of increased environmental regulation (Majsztrik et al., 2011). Therefore, the ornamental horticulture industry must strike a balance between the oftentimes competing interests of maintaining profitability and protecting water resource quality in combination when planning strategies in nursery and greenhouse crop production. The pressure to conduct these tasks in tandem with stricter discharge limitations argues for wider implementation of BMPs in the production process.

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Virginia nursery and greenhouse grower survey of best management practices

Summary. A survey was designed and then conducted with Virginia nursery and greenhouse growers, focusing on the use of irrigation and fertilization best management practices (BMPs). Objectives of the survey were to determine the most widely used BMPs, to assess the reasons for their use, and identify barriers to BMP adoption. The survey used Qualtrics, a survey tool, and was distributed in person, via email attachment, or link, to 357 Virginia growers in 2016; sixty growers responded to the survey. Survey results demonstrate that the most widely used BMPs included irrigation scheduling, integrated pest management (IPM) implementation, altering irrigation practices to optimize irrigation efficiency, controlled-release fertilizer (CRF) use, and plant need-based watering. Growers selected environmental/resource savings as one of the most cited reasons behind BMP use for water, fertilizer, and runoff management. Cost was the most cited barrier to BMP adoption for all BMPs. Fertilizer management BMP implementation was primarily an economic decision. The value of determining the most widely used BMPs and impediments to BMP adoption is that we can 1) communicate this information to growers who currently do not employ BMPs to encourage BMP adoption, and 2) subsequently inform the regulatory community of BMP use. Increased BMP use can boost the potential for mitigating agricultural nutrient and sediment runoff into impaired waterways, including those adjacent to the Chesapeake Bay, and help growers increase efficiency of operation inputs such as water and fertilizer resources.

Introduction

Environmental impacts resulting from nursery and greenhouse production practices are major concerns to producers in the Mid-Atlantic and Southeast U.S. Contaminants (such as fertilizers and sediment) indirectly discharged from the agricultural production site are considered nonpoint source pollution, and contribute to the impairment of waterways downstream (Majsztrik and Lea-Cox, 2013). Nonpoint source water pollution can be, in part, mitigated by the use of best management practices (BMPs). BMPs include schedules or measures of activities that reduce or prevent agrichemicals or sediment from entering into the air or water (Bilderback et al., 2013). These practices can be used to reduce runoff, and minimize fertilizer and water use, in essence efficiently using resources while protecting the surrounding ecosystem.

Agriculture, including nursery and greenhouse operations, is considered a leading source of nonpoint source water pollution (U.S. EPA, 2005). To ensure human safety and protect the environment, the U.S. Environmental Protection Agency (EPA), issued a Total Maximum Daily Load (TMDL), which establishes limits the amounts of sediment and nutrients that can be discharged to tributaries of the Chesapeake Bay (U.S. EPA, 2010, 2015). The Commonwealth of Virginia is responsible for reducing nutrients such as nitrogen (N) and phosphorus (P) and sediment from point and nonpoint sources such as municipal wastewater treatment, agriculture, and urban stormwater. BMPs utilized by agriculture producers are important tools to meet clean water goals, and voluntary adoption of these practices by the nursery and greenhouse industry is needed to show a good faith attempt to meet these goals and to practice good land stewardship. Surveys (Fain et al., 2000; Garber et al., 2002) have found that container-grown plant nurseries can be proactive in decreasing negative environmental impacts during production by implementing BMPs. BMPs can aid ornamental crop growers in increasing production efficiency while reducing nutrient runoff output (Bilderback et al., 2013), although some BMPs may negatively impact production; for this reason, the latter are likely not to be widely used.

Virginia's nursery and floriculture crop sales exceed $213M annually and are significant economic components of the estimated $1.42B of ornamental crops sold in the Mid-Atlantic United States (NASS, 2012). Thus, assessing the impact on production as well as water quality is important. Knowledge and communication of the most widely used BMPs, and the challenges and benefits associated with the use of these BMPs, can encourage other growers to adopt these BMPs and therefore increase the number of growers assisting in meeting the demands associated with regulatory pressure.

Although the Virginia greenhouse industry and its BMP use has been profiled via a survey (Scoggins et al., 2003, 2004), a survey of the state's nursery and greenhouse BMP use has not been conducted. The objectives of this study were to survey Virginia nursery and greenhouse growers to determine 1) the most widely used BMPs, 2) the reasons behind BMP use, and 3) the barriers to BMP adoption. Findings will be communicated to nursery and greenhouse growers via Extension and trade publications with the goal of increasing grower awareness and adoption of BMPs.

Materials and methods

Pilot survey. To facilitate the development of a representative and objective grower survey, an institutional review board (IRB) -approved pilot survey (PS) was developed to test potential survey questions and determine grower perceptions of BMPs (Mack, 2016; Appendix I). The PS asked growers general information about BMPs and was conducted in-person or by phone. The PS was conducted in an interview format, and growers were not limited by time.

The PS administration process included the use of a phone contact script, an email contact script, a basic information sheet about the study, a consent form, and the PS itself. Thirteen Virginia growers were initially contacted in 2015 based upon their expected knowledge and use of BMPs, and all indicated a willingness to participate in the PS. However, due to extenuating nursery/greenhouse business schedules, only five participants completed the PS.

A consent form detailing the PS and its risks was signed by participating growers before the completion of the interviews. Survey respondents were permitted to withdraw from the study at any time. Growers were selected based on their expected knowledge and use of BMPs, based on Virginia Tech faculty recommendations. Grower use of BMPs was critical to the survey to obtain detailed BMP use and insights. Participant operations included three nurseries, one greenhouse, and one greenhouse/nursery combination. The PS information sheet, given to respondents prior to taking part in the pilot survey, briefly explained the purpose of the research and included examples of BMPs so respondents would answer interview questions based on a general knowledge of BMP concepts. Grower responses to the PS were recorded in a notebook. Operation sizes ranged between 25 and 400 acres, and all growers used BMPs. Gross sales of participating operations were $5M to $10M. Codes were used as identifiers for grower names to protect their confidentiality.

The 15-question PS asked each participant to identify BMPs used at the growing operation, the nature of the growing operation, gross sales, and information sources used in BMP implementation. Water and fertilizer use topics were the prime focus of the survey. Questions determined BMPs used in Virginia, probed barriers to their adoption, and questions were asked to delineate reasons behind BMP-related decisions. Grower perception of BMPs, such as whether growers identified certain practices as BMPs, was evaluated by the pilot survey. Cost effectiveness of BMPs was included to identify BMPs that provide useful benefits in cost reduction and production efficiency. The PS also covered water management-related issues that growers reported to investigators.

Main survey. An IRB-approved (IRB #15-720) -main survey (Mack, 2016; Appendix II) on BMP use was disseminated to 357 Virginia nursery and greenhouse growers via email attachment, Qualtrics (Qualtrics, Provo, Utah) link, or in-person at the Mid-Atlantic Nursery Trade Show (Baltimore, MD) beginning 6 Jan. 2016. Grower information was obtained through friends and faculty of the Virginia Tech Horticulture Department. The survey consisted of 22 questions, and an email reminder was used to encourage participation. Operations were selected for the survey if they were nurseries or greenhouses with at least one location in Virginia. As an incentive to participate in the survey, a pH/electrical conductivity meter was awarded to one of the participating growers as selected by lottery. The survey was closed on 22 Feb. 2016. Sixty growers responded to the survey, resulting in a 17% response rate. Completing the survey constituted consent for information to be used in research, and identifying information was kept confidential.

To understand which BMPs were most widely used and why, we asked growers participating in the main survey about BMPs that were identified in the pilot survey. All participants were asked the same questions, including whether they used BMPs. The main survey asked questions pertaining to BMPs in ornamental horticulture, including most widely used BMPs, respondents' perceptions of BMPs, and the pros and cons of BMP use. The survey instrument employed a combination of multiple choice questions, fill-in dialog box questions, and a section using a Likert scale design, with answers from 1-10, to accurately determine the degree to which respondents agree or disagree with the inquiry. Survey questions were based upon BMPs found in a literature search and through the PS. The survey provided a definition of a BMP, and provided an example of a BMP in the survey introduction. Consent to participate in the study was included in the Qualtrics tool. The main survey also questioned growers about their familiarity with BMPs and their usage of BMPs to allow investigators to differentiate between responses of knowledgeable growers and those whose lack of familiarity with a specific BMP could skew results. Had a participant's data not been useful due to a lack of familiarity with the subject matter, then that subject would have been considered an anomaly. Growers with multiple locations were asked to answer questions based upon their Virginia location(s). The use of each of ten surveyed BMPs was tested individually using Fisher's exact test, and operation types (nursery vs. greenhouse) were compared. There was no significant difference in BMP use among greenhouses, nurseries, and 50/50 (nursery/greenhouse) groups for each respective BMP, with p-values ranging from 0.22 to 1, thus, data were pooled for these three groups.

Results and discussion

Pilot survey. The PS results showed that the most widely used BMPs were integrated pest management (IPM), CRFs, and water recapture, including practices such as using ponds to recapture water (Table 1). Water management practices for optimizing irrigation efficiency were used by 4 of these growers. Irrigation scheduling was primarily grower determined or based upon plant need. In further discussion with the growers, they indicated concern with both quality and quantity of water available for use, and were more focused on on-site than off-site water. Fertilizer was applied using a combination of both CRF and liquid form for four of the operations, while one used liquid fertilizer only. Fertilizer decisions were largely made based upon plant need . Most growers treated their water with chlorine (data not presented). Growers initially underreported BMP use, and required further questioning for investigators to obtain a complete list of BMPs used at each site. Some growers reported that they saved money or resources with BMP use. Growers who mentioned BMP implementation costs were unable to provide cost estimates due to the complex and often interwoven nature of cost inputs such as time, material, portion of labor devoted to BMPs, experience level of personnel, and salaries of those devoted to BMPs.

Main survey. Participating greenhouse and nursery operations ranged in size from 0.33 to 900 acres. Median size of participating operations was 7.5 acres, and the mean size was 89 acres. Operation types consisted of those that were solely or mostly nursery (61%), solely or mostly greenhouse (27%), and approximately half-greenhouse, half-nursery (13%). All participating growers had operations in Virginia.

All 60 survey participants reported using BMPs. The most highly ranked (based on a Likert scale), and most frequently used, BMPs were irrigation scheduling, IPM, optimized irrigation efficiency, plant need based watering, grouping plants by water needs, use of CRFs, and on-site water capture and collection (Table 2). Therefore, water-related BMPs and CRFs were frequently used by responding growers.

Overall, the most cited reasons for grower BMP use for fertilizer, irrigation, or runoff management were saving money (77%), resource savings (86%), and environmental stewardship (84%), respectively (data not presented). Environmental stewardship was a shared reason for grower use of BMPs for fertilizer, water, and runoff management, indicating that growers are concerned about the environmental impacts of production practices. These observations have also been noted in other states. Fain et al. (2000) found that Alabama growers were concerned with environmental impacts and were willing to make changes in production practices, including the installation of BMPs. This suggests that growers are interested in increasing operation profits while also protecting the environment. Improved production efficiency and cost effectiveness are reported benefits of BMP use (Yeager et al., 2010). The extent of a grower's use of a BMP may not only be site specific, but also region specific (Schoene et al., 2006), which was why concentrating our survey on the nursery and greenhouse industry within a defined geographic area was important.

Irrigation management. Growers had multiple reasons for their use of BMPs in irrigation management, including developing water or other resource savings, environmental stewardship, and efficiency or business production reasons (Table 3). Virginia growers (current study) who noted "other" reasons explained their operations did not require irrigation, such as those that relied on rainfall. Water sources for irrigation included well water (50%), on-site pond, streams, or lake (37%), and other (12%). Growers who used other water sources reported combinations of water source types. Only one grower used an off-site stream or lake.

In a characterization of irrigation method, Virginia growers applied irrigation via overhead sprinklers (45%), an overhead-microirrigation combination (27%), or microirrigation (20%). Only 6% used mostly boom irrigation. Irrigation scheduling was grower-determined or based on grower experience (90%), with some growers also employing irrigation scheduling based on a set time or irrigation amount (27%). Only one grower used a sensor or weather-based model for irrigation scheduling. On a Likert scale, use of sensor-controlled irrigation was not highly ranked by participants (4.5/10), indicating that sensors are not widely used among responding Virginia growers. Irrigation management is directly connected to fertilizer management since fertilizer is generally leached following an irrigation event regardless of irrigation and fertilizer application method (CRF or applied as a liquid through the irrigation system). The impact of applied fertilizers exiting the growing area is especially relevant for growers who apply fertilizer through their irrigation lines (i.e., liquid feed) in which case fertilizer may be applied to containers and the spaces in between containers (Majsztrik et. al, 2011).

Fertilizer management. Monetary savings, efficiency or business production reasons, and environmental stewardship were the most cited reasons (≥ 70%) that explained grower use of BMPs in fertilizer management (Table 4). While the most selected reason for BMP use for fertilizer management was money savings, environmental stewardship ranked as the third most important reason. As businesspersons, greenhouse and nursery operators are cognizant of the importance of valuing both the environmental resources, such as water and land, needed to produce their products, and the economic considerations involved in balancing production efficiency with water quality.

Less cited reasons that explained grower use of fertilizer management BMPs included time savings, water or other resource savings, and regulatory compliance (Table 4). Fertilizer application methods varied among growers. Most respondents used a combination of CRF and liquid fertilizer (60%), while some growers used only CRF (31%). Fertilizer application decisions were made based upon plant appearance/need (87%), testing substrate solution (46%), referencing the fertilizer label (42%), and fertilizer cost effectiveness (21%).

Runoff management. We asked growers about their use of water capture and collection (data not presented). Use of water capture and collection frequency (89%) was higher than the results of the use of the same BMP in other surveys in Georgia (48%; Garber et al., 2002) and Florida (34%; Schoene et al., 2006). Growers reported that environmental stewardship (84%), water or resource savings (65%), and efficiency or business production reasons (45%) explained their BMP use for managing fertilizer runoff (fertilizer exiting growing area). Less cited reasons for using runoff management BMPs were regulatory concerns (35%) or savings in money (27%) or time (16%).

Nearly three-fourths of respondents were not concerned about sediment loss from growing areas (73%); the minority (27%) that expressed concern for sediment loss supplied comments on their runoff management methods. Write-in comments noted that the methods growers used to manage on-site sediment included maintaining vegetated grassed areas and ditches, sediment ponds, grading, gravel filters, cover crops, and drainage swales. These comments suggest that some growers are taking action to reduce nutrient and sediment runoff from container-grown plant production areas. In a study of container runoff in six states (including Virginia), Yeager et al. (1993) stressed the need for implementation of BMPs to decrease runoff nutrient levels that, in some cases, were found to be in excess of federal drinking water standards (a metric often used in studies of runoff). Runoff mitigation, including protecting water quality and reducing runoff amount, is therefore a major topic of concern for scientists and for growers who wish to implement BMPs to reduce runoff.

Barriers to BMP adoption. Growers were questioned on whether they had encountered barriers to BMP adoption. The majority of respondents (71%) indicated they had not encountered barriers. The 29% of growers who answered affirmatively were asked to explain what impeded them from adopting BMPs. Grower reasons for not adopting BMPs included cost (67%), the need for upgrades to be made first (53%), lack of equipment (33%), not enough time (33%), and lack of knowledge (27%). In an interpretation of these data, growers are apparently more likely to implement easy-to-install or low-cost BMPs. We hypothesize that when growers implement a BMP that requires more than minimal inputs of cost, time, equipment, or knowledge, the reason is likely due to necessity.

BMP impacts on operation and environment. Growers were asked to rate (minor, moderate, or major) the effect of BMP implementation on their cost savings and environmental impacts. Growers reported that BMPs had minor (40%) to moderate (50%) impacts on cost savings. Only 10% said that BMPs had a major effect on cost savings. The effect of implementation of BMPs on environmental impact was rated by participants as moderate (53%), major (35%), or minor (12%), indicating that most responding growers believe that BMP use has more than a minimal effect on environmental impact.

Participant comments. The survey included a fill-in-the-box section, which encouraged participating growers to list the top water management issues affecting their specific growing operations. Most responses included water availability or access, water quality, and water use or waste. Reasons behind these concerns likely vary by individual operation. Bilderback (2002) suggested that growers may be concerned about water waste, and may benefit from use of shut off valves in individual sprinklers to prevent water waste upon the removal of a crop from a particular irrigation zone. Schoene et al. (2006) noted that growers who use overhead irrigation may be concerned about the effect of water quality on plant appearance.

Education Growers reported that their sources of BMP information included learning on their own (81%), observing BMP use by other industry personnel (62%), extension publications (60%), vendors (21%), the BMP manual (13%), and other (12%). Because most growers receive their information by learning on their own or observing BMP use by others in the industry, efforts to increase BMP use should be conducted with these sources in mind. The BMP manual was not a direct information source for most responding growers.

Conclusions

BMPs were used by 100% of survey respondents, indicating that they are in common use in Virginia nursery and greenhouse commercial production operations. Furthermore, BMPs are used selectively in the industry to minimize and increase efficiency in water and fertilizer use, and to reduce production costs. Survey results indicate that growers are cognizant of both business and environmental issues and concerns. Communication of these results via Cooperative Extension and trade publications can educate growers on BMP use in ornamental production and help encourage BMP adoption by growers who do not use or have limited use of BMPs. Our results begin to address reasons behind grower BMP use, and the barriers to BMP adoption. Based on our survey results, the Virginia industry best learns from other industry growers, learning on their own, and through cooperative extension. Therefore, we hypothesize that focusing on BMPs that are currently being implemented by growers can lead to increased BMP adoption resulting in a decreased amount of agricultural nutrients and sediment runoff into impaired waterways. Additionally, growers can make more efficient use of inputs, such as fresh water, with increased BMP use. Increasingly strict water quality standards casts BMPs as both fundamentally relevant and viable tools to empower growers wishing to balance the often competing issues of environmental stewardship and operation productivity.

Further research is needed to determine the scientific merit of the numerous BMPs prescribed for the greenhouse and nursery industry. While there is a general consensus of the use of the BMPs surveyed, there is a need to link specific BMPs with the associated relevant peer-reviewed publications, thus validating them for the growers. This validation should increase the potential impact of the BMPs. With increasing demands on both land and water resources, environmental and production goals should each receive consideration. As BMPs are the tools to minimize production impacts on the environment, BMP use will likely increase in the future within ornamental crop production.

Table 1. Pilot survey was administered to five operations that self-identified as follows: one greenhouse, three nurseries, and one combination nursery/greenhouse. (n=5). Respondents were asked open-ended questions about best management practice (BMP) use.

What BMPs do you use?	
BMP	**Number of respondents**
Integrated pest management	5
Controlled-release fertilizers	5
Pond(s) to recapture water	5
Grass strips	4
Water management practices	4
Drip irrigation	4
Recycling water	3
Filter socks	2
Grouping plants with similar needs	1
How do you make fertilizer decisions?	
Plant need	4
Testing: EC/pH/chlorine levels	3
Based on timing of crop finishing	1
Past experience	1
Fertilizer label	1
Cost effectiveness	1
How do you schedule irrigation (plant need, set schedule, sensors)?	
Grower determined or plant need	3
Computerized	1
Cyclical/on a timer	1
Sensors	1

Table 2. Average rating and number of responding nursery and greenhouse growers using selected best management practices (BMPs) on the main survey (n=60) for a 1-10 Likert scale question: My nursery/greenhouse operation implements the following production or management practice(s). A rating of 1=strongly disagree and 10=strongly agree. This table presents those BMPs that merited responses from over 80% of participants.

BMP	**Average rating**	**Number responding**
My nursery/greenhouse operation implements the following production or management practice(s).		
Irrigation scheduling	9.0	48
Integrated pest management	8.5	53
Optimized irrigation efficiency	8.4	49
Plant need based watering	8.3	51
Grouping plants-water need	8.1	52
Controlled-release fertilizer	8.0	52
Water capture/collection	7.5	51

Table 3. Reasons main survey participants use best management practices in irrigation management (n=56) and answered the following question: Why do you use BMPs in irrigation management (check all that apply)?

Reason for use	Percent respondents[z]
Saves water or other resources	86
Environmental stewardship	77
Efficiency/business/production reasons	71
Saves money	59
Saves time	52
Legal compliance/regulatory violation concern	25

[z]Percentage of 56 respondents who used BMPs for irrigation management.

Table 4. Reasons main survey participants use BMPs in fertilizer management (n=56) and answered the following question: Why do you use BMPs in fertilizer management (check all that apply)?

Reason for use	Percent respondents[z]
Saves money	77
Efficiency/business/production reasons	71
Environmental stewardship	70
Saves time	48
Saves water or other resources	41
Legal compliance/regulatory violation concern	30

[z]Percentage of 56 respondents who used BMPs for fertilizer management.

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Linking scientific reports to selected water-related best management practices for the nursery and greenhouse industry

Summary. Nursery and greenhouse growers use a variety of science-based practices known as best management practices (BMPs) to reduce sediment, nutrient, and water losses from growing sites and to improve production efficiency. While these BMPs are almost universally recommended in guidance manuals, little information is available that links specific BMPs identified in grower recommendations to scientific literature that supports their use and quantifies their effectiveness. In a previous manuscript, we identified the most widely used water management, runoff, and fertilizer-related BMPs by Virginia nursery and greenhouse operators. In this manuscript, the applicable literature was reviewed and assessed for factors that influence the efficacy each BMP and metrics of effectiveness such as reduced water use, or reduced sediment, nitrogen (N), and phosphorus (P) loading in runoff. BMPs investigated were vegetative zones, plant need-based watering (including deficit irrigation), leaching fraction, and controlled-release fertilizers (CRFs). By linking BMPs to empirical reports, individual BMPs are thus validated from the perspective of both growers and environmental regulators. In the face of current and impending water use and runoff regulations, validating the use and performance of these BMPs will lead to increased adoption, minimizing water use and nutrient loss from growing sites.

Introduction

Irrigation of container-grown plants is usually needed on a daily basis due to a limited water-holding capacity in planting media. Media (also termed substrates) are chosen to optimize total air space (pore space) for plant growth and to minimize diseases. This results in water and agrichemicals exiting the container. Irrigation runoff from growing areas can contaminate on-site water storage or receiving surface water bodies. Nursery and greenhouse operators are concerned with the environmental impact of their production practices on irrigation water quality, and with the decrease in efficiency associated with resource losses. Best management practices (BMPs) defined, in part for the nursery industry, are a variety of specific measures or activities designed to reduce water and fertilizer use, and to decrease fertilizer runoff and eventual pollution (Bilderback et al., 2013). A BMP for the ornamental industry is designed to increase plant production efficiency as well as have a positive environmental effect, whereas a BMP for the purposes of the Clean Water Act is designed to have an environmentally positive effect, but not necessarily efficient. More efficient delivery of irrigation water minimizes runoff. Runoff exiting production sites is considered nonpoint source pollution by the Environmental Protection Agency (U.S. EPA, 2005). The purpose of the Southern Nursery Association's *Best Management Practices Guide: Guide for Producing Nursery Crops* (Bilderback et al., 2013) was to identify BMPs for specific site issues and to promote environmental stewardship. This guide outlined management practices that reduce or prevent nonpoint source pollution or waste from entering into water. However, while BMPs were identified, they were not specifically linked to scientific literature articles nor was their effectiveness assessed.

The gradual eutrophication of the Chesapeake Bay from excessive sediment and nutrients in discharges upstream is a driver for BMP implementation. The Chesapeake Bay Watershed (CBW) is approximately 1.66×10^5 km^2 in size and consists of large portions of Delaware, Maryland, New York, Pennsylvania, Virginia, West Virginia, and the District of Columbia.

Approximately two-thirds of Virginia is within the CBW. The U.S. EPA considers agricultural runoff to be a leading source of nonpoint source pollution to the Bay and has placed limitations on nutrient loads discharged in the CBW (U.S. EPA, 2010). These reductions are goals intended to restore clean water in the Chesapeake Bay by the year 2025. Irrigation and nutrient runoff management BMPs are the prescribed tools which the nursery sector can use to meet clean water goals (Majsztrik and Lea-Cox, 2013). In the Mid-Atlantic region, nursery and floriculture crop annual sales exceed $1.42B (National Agricultural Statistics Service, 2012), and there is a formidable challenge to growers in the relatively large industry to employ BMPs and to be responsible environmental stewards while not adversely impacting production efficiency.

Due to the unique needs of container-grown crops, managing water on- and off-site poses a significant challenge. Adoption of BMPs can help growers maintain production efficiency while reducing resource use and preventing potential nutrient runoff from entering into 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, 2016), particularly if it can become a market differentiation with potential customers. Critical to adoption of proposed container crop BMPs is the identification of scientific studies validating their performance for the intended use. The objective of this work is to document the scientific literature that supports the use and performance of selected water-related and fertilizer-related BMPs, thus providing scientific substantiation for growers to voluntarily adopt them. This can lead to broader acceptance of these BMPs by growers and regulators.

Materials and methods

A 2016 survey of Virginia nursery and greenhouse growers 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 need (Mack, 2016). While integrated pest management was also a frequently used BMP, irrigation-related practices are a driver of nutrient loss from container-grown plants (Tyler et al., 1996b). This work therefore focuses on irrigation and controlled-release fertilizer (CRF) BMPs, such as the use of vegetative zones, cyclic irrigation, plant need based watering, deficit irrigation, leaching fraction, and CRFs. This work identifies the science-based information from refereed journal articles supporting the use of these BMPs. We conducted a literature search to identify supporting scientific literature. Refereed journal articles chosen for inclusion in our analysis were selected based upon their relevance to the application of the BMP in reducing nutrient runoff or irrigation water waste for container grown plants.

Results and discussion

Vegetative zones.

Vegetative zones were identified as a frequently used BMP for managing runoff at the production site, and were used by 76% of responding growers in Virginia (Mack, 2016). Vegetative zones are defined as vegetated strips of land consisting of grass or plant species through which runoff from production areas where the water is not being captured by collection structures is directed. A VZ can be as simple as a section of grass maintained alongside a production area. Vegetative zones mitigate sediment by increasing the surface area exposed to runoff, decreasing velocity, and leading to increased infiltration into the VZ (Borin et al., 2005; Liu et al., 2008). Nutrient concentrations are reduced through settling, uptake, and infiltration into the soil (BMP #39 in the *Best Management Practices Guide*: *Guide for Producing Nursery Crops* (Bilderback et al., 2013). One way to manage runoff from the production site is through the use of vegetative zones (VZs). In this way, VZs are similar in function to urban stormwater BMPs known as vegetated filter strips or sheetflow to open space (Sample and Doumar, 2012). In this paper, for consistency, we will refer to each BMP by number as they are ascribed by Bilderback et al. (2013).

Numerous studies have demonstrated that VZs are effective in filtering sediment from runoff (Table 1; Helmers et al., 2005, Schmitt et al., 1999). The efficacy of VZs for sediment removal has been found to range 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), which is the width suggested by regulatory guidance (Majsztrik et al., 2011). Geza et al. (2009) and Mayer et al. (2007) found that wider vegetative strips (>50 m) tended to be more consistent at sediment and nitrogen removal, respectively, than narrower strips, while Zhang et al. (2010) found that enlarging the VZ width from 5 m to 10 m improved sediment removal by 10% to 15%.

However, wide strips are not always necessary for good filtration. Gharabaghi et al. (2006) reported that over 95% of larger sediment sizes in runoff were trapped in the first 5 m of the VZ (Table 1) . In a review of VZs, a wider VZ (20-m) was found particularly effective at removal of fine particles, since residence time (the average time the particles stay in suspension) is increased in comparison with the 5 m width (Liu et al., 2008). In a VZ, sediment particles may infiltrate, along with water, into the soil (Liu et al., 2008), with heavier sediments trapped on the surface, and finer sediments penetrated deeper. VZs are also used to reduce nutrients in runoff waters exiting production sites. VZs reduced nitrate concentrations in runoff by 24% to 48% (with rainfall dilution), total nitrogen by up to 95% (Li et al., 2016; Schmitt et al., 1999), and reduced total P in runoff water by 27% to 97% (Uusi-Kamppa et al., 2000). Up to 82% of runoff volume can infiltrate a VZ, reducing runoff (Schmitt et al., 1999). Increasing VZ width from 7.5 m to 15 m increases infiltration by double (100% more) (Schmitt et al., 1999). Variables such as soil moisture content, and subsurface chemistry (Geza et al., 2009) should be taken into account when considering VZ design.

The type of vegetation used in a VZ can affect the effectiveness of nutrient and sediment mitigation. Growers interested in containing certain contaminants should construct their VZs according to the vegetation type that can best control that contaminant. Zhang et al. (2010) found that VZs consisting of trees had greater N and P removal efficacy than 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 zone use is a cost effective method for nutrient and sediment reduction (Majsztrik et al., 2011). Bohlen et al. (1914) found that cost and economic returns are the most important factors affecting the speed in which a farm practice, such as a BMP, is adopted. The true lifecycle cost of VZ implementation includes 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 of the loss of potentially productive land allocated to the use of the BMP. Cost of a VZ may be distributed over years (Geza et al., 2009). Placement of the VZ is important to its cost effectiveness. Geza et al. (2009) found that using grassed waterways, or return ditches, was more cost effective at reducing sediment load into receiving streams than replacing specific agricultural areas within a watershed with VZs; smaller VZs over a large area were more effective than larger strips in fewer selected areas. Zhou et al. (2009) found that VZ establishment was about $86.00/acre in year 2008 dollars while annual maintenance was approximately 5% of the establishment cost, and estimated VZ life span at 10 years.

Water management

Cyclic irrigation.

Irrigation scheduling was used by 89% of responding growers in Virginia (Mack, 2016). Cyclic irrigation is a type of irrigation scheduling used to increase resource use efficiency and decrease water use. Cyclic irrigation appears as BMP #13, and is defined as irrigation that divides an individual plant's daily water allocation into multiple applications (Bilderback et al., 2013). Water availability is important for growers of nursery and greenhouse crops in accommodating production cycles in which plants experience periods of rapid growth. Maintaining adequate substrate moisture levels can be challenging for growers of container crops, and with increasing regulatory pressure to limit water use, tools such as irrigation management BMPs may assist growers in optimizing their water use. One irrigation management method to minimize water use is cyclic irrigation. Nursery utility of cyclic irrigation was first reported in 1986 (Whitesides, 1989), and growers use the practice as a simple means of optimizing crop irrigation through more efficient water use and thus improving water management. For many growers, cyclic irrigation can be applied without making significant changes in their irrigation equipment or setup (Fain et al., 1999); however, some growers may need to modify an existing irrigation setup or schedule to employ the multiple water applications involved in cyclic irrigation. Research on cyclic irrigation found that using a simulated overhead irrigation system, increased water application efficiency (irrigation effectiveness at applying and retaining water in the container substrate) compared with a single application (Karam and Niemiera, 1994). Potentially, a 10% or higher increase in water application efficiency can be achieved using spray stakes over single application irrigation using spray stakes (Lamack and Niemiera, 1993). A review of studies demonstrating the effectiveness of cyclic irrigation appear in Table 2. Tyler et al. (1996a) found an average 38% improvement in irrigation application efficiency over single application when applied via pressure compensated drip emitters to *Rudbeckia fulgida* Ait. 'Goldsturm' and *Cotoneaster dammeri* Schneid. 'Skogholm'. This increased water efficiency associated with cyclic irrigation makes this practice particularly attractive for growers interested in optimizing water use in their production cycles.

The management of water and nutrients is an essential and integral part of containerized plant production. Cyclic irrigation improves water application efficiency, thus increasing the retention of water in the container, through overhead sprinklers or microirrigation (spray stakes or drip irrigation) (Karam and Niemiera, 1994; Warren and Bilderback, 2005). Many growers apply a standard single application of irrigation to their container crops as part of their routine production practices. While a daily standard single irrigation application can produce quality plants, it is not a viable practice for operations interested in limiting water use, and intermittent application is more water efficient (Morvant et al., 1998).

Cyclic irrigation reduces container leachate nutrient losses, and provides growers more control over crop nutrient management. In a comparison of cyclic to single application irrigation, Tyler et al. (1996a) found that cyclic irrigation resulted in a reduced volume of effluent (17.7% less), and 25.6 fewer grams (50% less) total NH_4-N lost than single application irrigation. Karam and Niemiera (1994) found that cyclic irrigation reduced N losses from containers by 43%, increased plant tissue N concentration 0.7% (absolute basis), and resulted in 43% higher root dry weights compared to that of a single application irrigation.

Tyler et al. (1996a) found that shoot and root growth of *Rudbeckia fulgida* Ait. 'Goldsturm,' 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 not affected by the irrigation method. Beeson and Keller (2003) found that cyclic irrigation applied using micro-spray heads increased *Magnolia grandiflora* ex DC height, as well as trunk diameter, compared to single application. Similarly, Fain et al. (1999) found that *Quercus acutissima* Carruth. growth (height and trunk diameter) was greater with cyclic irrigation than plants with single application.

Plant need-based watering.

BMP #14 states, "[a]mount of water applied to production areas should be based on plant needs" (Bilderback et al., 2013). Plant water needs can vary depending on factors such as weather, time of year, container and plant size, substrate, 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 *Rhaphiolepis indica* Lindl. may reach marketable quality when grown in up to 80% water deficits, while species such as *Viburnum odoratissimum* Ker Gawl and *Ligustrum japonicum* Thunb. would be negatively affected by water application reductions (Beeson, 2006).

In a study of container-grown woody ornamentals, including *Deutzia gracilis* Seib. and Zucc. 'Duncan', *Thuja plicata* D. Don 'Atrovirens', *Kerria japonica* (L.) D.C. 'Albiflora', and *Viburnum dentatum* L. 'Ralph Senior', irrigation applied at 100% and 75% of daily water use (calculated by determining volume of substrate water lost), resulted in 66% and 79% less potential operation runoff volume than the control application of 19 mm per day (Warsaw and Fernandez, 2009). Less NO_3-N and PO_4-P were leached in the 100 and 75% treatments than the control, less water volume (38% and 59%, respectively) was applied than the control, and resulted in plants of similar or larger size. The BMP manual (Bilderback et al., 2013) contains a reference list of water requirements for many container-grown species and growers may use this list to match watering practices to individual taxa requirements, or choose taxa for an existing irrigation system.

Research has established that growers are using plant need-based watering as a BMP (Garber et al., 2002; Mack, 2016). Garber et al. (2002) surveyed Georgia growers and found that frequency of use of need-based watering (17%) was equal to that of water recycling as a water conservation practice. Mack (2016) found that plant needs-based watering was rated 8.29/10 on a Likert scale of use among surveyed Virginia growers. A disadvantage of plant-need based watering is the potential need for altering operation practices by changing plant spacing, adding sensors, or modifying irrigation systems, for implementation (Davies et al., 2016).

Deficit irrigation.

The concept of deficit irrigation is to supply only the amount of water needed by the plant for growth. Deficit irrigation can be incorporated into irrigation scheduling to better manage water use. In practice, deficit irrigation involves watering at low levels, or targeting irrigation to be delivered during drought sensitive stages of growth; reviewed articles shown in Table 3. One option for implementing deficit irrigation is limiting irrigation to a percentage of the water holding capacity of the substrate (Ahmed et al., 2014).

Plant growth stage is affected by deficit irrigation. Alvarez et al. (2013) studied deficit-irrigated *Pelargonium* X *hortorum* L. H. Baily plants grown in peat, pearlite, 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 flowers when deficits were applied at flowering (Alvarez et al., 2013). Therefore, plant quality is determined by the stage of development when deficit irrigation was applied.

Davies et al. (2016) found that a value-added benefit of deficit irrigation was controlled growth in woody ornamentals. Welsh and Zajicek (1993) found that plant growth was maximized at a

25% deficit, above which growth was limited (Table 3). However, a potential drawback of deficit irrigation is that it could affect crop production time. Beeson (2006) cautioned that water restrictive irrigation regimes can reduce plant size, which can prolong production time, thus negating the water savings underpinning the use of the irrigation practice. However, drought tolerant species can reach marketable status under water deficit growing conditions (Beeson, 2006). Limiting water losses occurring through evapotranspiration is important in the use of deficit irrigation. To maximize water application efficiency, the retention of substrate-applied water must be maximized (Warren and Bilderback, 2005). Lamack and Niemiera (1993) found that a deficit of 600 ml medium moisture resulted in a 65% water application efficiency, and that dry substrate can be hydrophobic, leading to channeling and reducing efficiency. Accordingly, growers should weigh their goals and practices carefully when considering water limiting irrigation regimes for overall water use reduction. Growers may choose to modify their specific water application practices to use overhead irrigation to water deficit irrigated plants rather than using drip irrigation (Davies et al., 2016). This permits growers who do not have specialized equipment to adopt deficit irrigation as a crop management practice. Additionally, decreased water applications reduce leachate by decreasing water available to leach from containers (Davies et al., 2016), reducing the potential for nutrient runoff from production sites. Avoiding the application of excess water reduces total water available to exit production sites, therefore preventing runoff (Fulcher and Fernandez, 2013b), so this BMP can help in meeting clean water goals.

Of course, all water use reduction strategies must maintain commercially acceptable plant quality to be viable (Beeson, 2006). Beeson (2006) compared different deficit irrigation amounts to a control irrigation application of 18 mm daily for *Rhaphiolepis indica* Lindl., *Viburnum odoratissimum* Ker Gawl, and *Ligustrum japonicum* Thunb. When qualitative evaluations for commercial acceptability were made by growers, and compared to standard quality plants, growers rated deficit-irrigated plants more negatively than the standard. This single example validates the concept that deficit irrigation should not be implemented without consideration of individual grower and end-consumer opinions on plant quality. 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 crop and climate.

Leaching fraction management.

Leaching fraction (LF) is another measure that growers can use to manage irrigation. In essence, LF is a unitless measure of the fraction of water that exits a container relative to the amount of water that was applied. For example, if 100 ml water was applied to a container and 10 ml exited the container, then the LF – 0.10 (or 10% of the applied volume was leached). Leaching fraction, BMP #17, is a calculation that aids growers in determining irrigation application excesses, and is calculated by the following division:

$$\frac{\textit{leachate volume}}{\textit{total volume of irrigation applied}}$$

with high LFs (>0.2) signaling that excessive irrigation is being 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 irrigation use efficiency. Irrigation use efficiency is measured as:

$$\frac{\textit{plant dry weight}}{\textit{(volume irrigation water applied-volume irrigation water leached)}}$$

and leaching fraction also reduces nutrient leaching (Tyler et al., 1996b). Tyler et al. (1996b) compared spray stake-irrigated rooted cuttings of *Cotoneaster dammeri* Schneid. 'Skogholm' grown under low (0.0 to 0.2) vs. high (0.4 to 0.6) LFs, and found that irrigation use efficiency was 29% higher with those grown under the low LF regimen. A low LF regimen had a 44% lower irrigation volume, a 63% lower effluent volume, and 66%, 62%, and 57% reductions in cumulative NO_3-N, NH_4-N, and P effluent contents (Tyler et al.,1996b). However, this increase in efficiency reduced shoot and root growth by 10% (compared to higher LF), indicating that growers must balance the benefits of increased efficiency against the potential effects on plant growth (Tyler et al., 1996b). A similar result was found by Ku and Hershey (1992), who noted that growth of *Pelargonium*x*hortorum* L.H. Baily 'Yours Truly' was reduced under low LF (0 and 0.1), and that plants with LF of 0.2 and 0.4 had 37% higher shoot dry mass. Decreases in growth associated with low LF may be caused by soluble salt buildup or water stress. The LF that affects plant growth may be a matter of degree and species used, as Owen et al. (2008) found that reducing LF from 0.2 to 0.1 on *Contoneaster dammeri* Schneid. 'Skogholm' containers decreased effluent volume 64%, but did not affect plant dry weight.

Niemiera and Leda (1993) conducted a column experiment with an irrigation regimen of 5 days a week for 12 weeks to determine the effects of various LFs on N losses from a CRF and N leached from pine bark. Bark at LF of 0.4 had 61% more N leached than that at LF of 0.2, and solution NO_3 concentrations were higher at low LF (0) than at high LF (0.4). LF did not affect the CRF release rate, but lower LF resulted in more plant available N, and less N losses through leaching (Niemiera and Leda, 1993).

LF may be used with other growing practices to reduce nutrient waste such as by placement of CRF in the 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 vs. incorporated placement containers. Method of fertilizer application can therefore work in concert with the use of low LF to reduce nutrient leaching in containerized production.

LF may affect electrical conductivity (EC; a measure of fertilizer salt concentration) of the substrate solution (Fulcher and Fernandez, 2013a). Growing plants at irrigation volumes that just meet plant daily water use can result in low LFs and result in soluble salt accumulation in the container substrate (i.e., a relatively high EC value), which is potentially damaging to plants (Warsaw and Fernandez, 2009). Warsaw and Fernandez (2009) found that EC of container-grown *Deutzia gracilis* Sieb. and Zucc. 'Duncan,' *Kerria japonica* (L.) DC. 'Albiflora,' *Thuja plicata* D. Don 'Atrovirens,' and *Viburnum dentatum* L. 'Ralph Senior' was highest after a period when irrigation was not applied during the experiment, and they attributed this finding to soluble salt accumulation. Therefore, growers using low LF regimens to limit nutrient losses from leachate should monitor EC to ensure soluble salts do not buildup in containers, especially in low precipitation periods (Fulcher and Fernandez, 2013a). If soluble salt levels rise, LF may be increased or containers may be flushed. A disadvantage of LF is that larger containers may be more difficult to handle, and therefore more difficult to sample (Yeary et al., 2015).

Knowledge of LF values benefits growers by providing a picture of irrigation water application excesses and deficits. Growers with high LFs can reduce water application and increase efficiency. Nutrient runoff may be reduced by using low LF via a decrease in water applied, and therefore available, to exit production areas. A drawback to low LF is that growers may need to monitor soluble salt levels to avoid reductions in plant growth.

Controlled-release fertilizers.

Controlled release fertilizers are coated fertilizers that work by releasing nutrients gradually over time. CRFs are considered to be efficient because they release nutrients over a span of time rather than all at once (Broschat, 1995, Rathier and Frink, 1989). In an effort to minimize nutrient runoff CRFs have been used as a practice to prevent contaminant discharge into waters, and appear as BMP #98 in the aforementioned BMP manual (Bilderback et al., 2013). CRFs can reduce the potential for contamination of surface water by decreasing the amount of nutrients in leachate (Broschat, 1995; Godoy and Cole, 2000). CRFs are primarily used in nursery production. CRFs may also be used to reduce nutrient losses and soluble salt injuries in container-grown plants (Broschat, 1995). An overview of cited CRF articles is shown in Table 4.

The most commonly found N form in leachate (73% to 85% of total N leached) was NO_3-N (Cox, 1993; Million et al., 2007). 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, NO_3 in nearby water may exceed concentrations permitted by drinking water standards (Yeager et al., 1993), and contribute to nutrient loads in impaired waterways. Application of fertilizer though fertigation, or soluble fertilizer dispensed via the irrigation system, can be inefficient if delivered through overhead irrigation (Sammons, 2008). Shoot dry weight has been found to be equal to or lower for plants grown with CRF versus liquid fertilizer (Broschat, 1995, Cox, 1993). Therefore, in a comparison to fertigation, CRFs have the potential to produce equal sized plants with greater efficiency for containerized production. Some growers may choose to use a combination of CRF and liquid feed. In a comparison of liquid feed, CRF, and a combination of CRF and constant liquid feed, the combination of constant liquid feed and CRF produced *Rosmarinus officinalis* L. plants with reduced shoot weight and plant height (Boyle et al., 1991). Boyle et al. (1991) hypothesized that the combination treatment may have suppressed plant height due to increased salinity or nutrient imbalance.

Controlled release fertilizer application practices, such as time of application and placement, can affect fertilizer efficiency. Some growers incorporate or apply CRFs at the time of potting (Majsztrik et al., 2011). Early N losses when 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 irrigation method employed (Cox, 1993; Table 4). Cox (1993) found that N losses were highest in the first 30 days after CRF application, and that over 50% of the total N (mostly NO_3-N) leached was collected during this time. These data support the concept that NO_3-N losses (higher leachate concentrations) can occur when fertilizer 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). The early season spike in NO_3-N loss was attributed to release of fertilizer at concentrations above that which could be readily used by the plant. Less N was recovered in leachate when 2 to 3 month or 70 day CRFs were surface applied, rather than incorporated, at the same rate (Cox, 1993). This may be because intermittent drying results in slower release of nutrients from CRF fertilizer when it is applied to the surface of the substrate (Broschat, 2005).

In a study of nutrient leaching in container-grown tropical foliage plants, Broschat (1995) found that nutrient leaching was greatest for soluble granules and lowest for a 3 to 4 month CRF surface applied every two months, or a 12 to14 month CRF applied once. Between 11% and 28% of PO_4-P applied was leached from all fertilizer treatments. Over the 6-month experiment period, PO_4-P leaching generally increased, then decreased after week 22, and leachate PO_4-P was higher for plants grown with liquid fertilizer or soluble granules than for those grown with CRFs. The PO_4-P leaching curve demonstrated that magnitudes of nutrient leaching correlated with timing of rainfall events.

The efficacy of CRFs in reducing N and P leaching and runoff compared to fertigation is not clear cut, as the potential for reducing N and P losses likely depends on the employment of cultural practices in support of the desired nutrient loss reduction. Cultural practices that affect 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 hydraulic conductivity of soilless substrate, there is increased leaching of P as compared to similarly amended mineral soil (Yeager and Ingram, 1985). Another cultural practice which may benefit growers is the use of drip or trickle irrigation, which can work in concert with CRFs to conserve water (Bilderback, 2002), and therefore reduce the potential for nutrient leaching from the container. Containerized crops are frequently planted in porous substrate, and irrigated daily, potentially leading to increased nutrient loss (36% more leaching of NO_3-N than with drip irrigation when overhead irrigation was used), particularly if overhead irrigation is used (Rathier and Frink, 1989).

Controlled release fertilizer can reduce N and P losses, but implementation of appropriate cultural practices also supports such reductions. Practices that support the reduction of nutrient losses include the utilization of multiple CRF applications (may be topdressed) rather than large single dose incorporation, and the use of drip or trickle irrigation. When a short term CRF was used in multiple applications, and compared to a single application of a long term CRF at the same rate, the short term fertilizer resulted in the least (34% less) PO_4-P lost in leachate (Broschat, 1995). New, long-term CRFs have improved nutrient release as compared to older CRF fertilizers. 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 nutrients in container leachate and runoff from growing operations.

Controlled-release fertilizer can be used by growers to increase fertilizer efficiency while potentially reducing nutrients exiting containers. Plants grown with CRFs may be of equal size to those grown with fertigation. A drawback to CRFs is that crops with comparatively short production cycles may be finished before CRFs can release, and therefore CRFs are better suited to crops without very short production cycles. However, when CRFs do not fully release during production, consumers can benefit from the remaining f0ertilizer released by CRFs (England et al., 2012). Application of CRFs can also be labor intensive, particularly if manually spread via surface applications. CRFs can be more expensive than liquid feed, but less management is typically needed to grow crops with CRFs. With the use of long-term CRF formulations, growers may find that the potential drawbacks of CRF use are not dispositive.

Summary and conclusion

Our objective was to link water-related BMPs with the literature supporting their use. Growers face increasing regulatory pressure to produce plants with less water and fertilizer use, and BMPs help growers to increase resource efficiency while reducing discharge loads of nutrients and sediment, permitting growers to contribute to environmental restoration of receiving waters. Growers are cognizant of environmental concerns, and readily adopt BMPs to reduce water use and reduce fertilizer loss from the production area (Mack, 2016). A benefit of BMPs is that exact BMPs adopted by an operation may be tailored to the specific needs of the operation, and water management BMPs aid in reducing the potential for water related contaminants entering receiving waters. Irrigation decisions are largely made based upon grower experience in working with the plant material and its specific water needs for optimal growth. The individual species growing requirements, climate conditions, and grower preferences in crop production, such as substrate and fertilizer type, highlight the complexity of production decisions for 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 towards the flexibility offered by water management BMPs as tools for growers to meet production goals while reducing adverse impacts on protected waters. We have linked the relevant scientific evidence to the BMPs to provide growers solid support and confidence in using BMPs for ornamental horticulture water management. Increasing uniformity across scientific papers for BMP research will permit more detailed comparison, 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.

Table 1. Vegetative zone (VZ) efficacy in nutrient and sediment mitigation as demonstrated in reviewed studies by vegetation type and location.

Vegetative zone characteristics

Author(s)	Location	Vegetation type	VZ efficacy
Patty et al., 1997	France	rye grass	nitrate reduced 47-100%
Schmitt et al., 1999	USA	various (grass, sorghum, trees & shrubs)	nitrate reduced 24-48%, nitrogen by up to 95.2%
Uusi-Kamppa et al., 2000	Finland, Norway, Sweden, and Denmark	grasses and vegetation	Reduced phosphorus in runoff 27%-97%
Syversen, 2005	Norway	grass, aspen, mountain ash, birch	N removal efficiency, 37-81%
Liu et al., 2008	USA	Varied	Sediment removal efficacy 45%-100%
Li et al., 2016	China	arrowhead, wild rice, calamus	Total N removal rates, 90.6% and 95.2%

Width

Author(s)	Location	Vegetation type	VZ efficacy
Abu-Zreig et al., 2004	Canada	Varied	68% at 2-m wide to 98% removal at 15-m wide
Helmers et al., 2005	USA	Blue stem, switchgrass, Indiangrass	80% effectiveness at sediment removal with 15 m VZ

Author(s)	Location	Vegetation type	VZ efficacy
Gharabaghi et al., 2006	Canada	Varied	Over 95% of larger aggregates trapped in the first 5 meters of buffer strip
Mayer et al., 2007	Varied (review)	Varied	VZs >50 ft were more consistent at nitrogen removal
Zhang et al., 2010	Various (review article)	Varied	Enlarging the buffer strip from 5 to 10-m added 10%-15% more sediment removal

Table 2. Cyclic irrigation effectiveness in water and nutrient management as reported in reviewed articles, by species and substrate type.

Author(s)	**Location**	**Species/substrate**	**Cyclic irrigation efficacy**
Lamack and Niemiera, 1993	USA	*Tagetes erecta* L. 'Apollo'/Pine bark filled containers	10% or greater increase in water application efficiency
Fare et al., 1994	USA	*Ilex crenata* 'Compacta'/pine bark: peat 3:1	Leachate volume reduced 34% over single application N leached as $N0_3$-N decreased from 63% (single cycle) to 46% (3 cycles)
Karam and Niemiera, 1994	USA	*Tagetes erecta* L 'Apollo'/pine bark	Water application efficiency increased 4% Reduced nitrogen losses from containers 43% 43% higher root dry weights compared to single application
Fare et al., 1996	USA	*Ageratum houstonianum* Mill. 'Blue Puffs'/pine bark:sand 6:1	Leachate volumes decreased 54%; Total N leached 47% less
Tyler et al., 1996a	USA	*Rudbeckia fulgida* Ait. 'Goldsturm' and *Cotoneaster dammeri* Shneid. 'Skogholm'/pine bark: sand 8:1	38% increase in irrigation efficiency over single application
Fain et al., 1999	USA	*Quercus acutissima* Carruth. / pine bark 100%, and pine bark: coir 4:1	Growth (height and trunk diameter) greater than with single application

Author(s)	Location	Species/substrate	Cyclic irrigation efficacy
Beeson and Keller, 2003	USA	*Magnolia grandifolia* ex DC/deep sand soil	Increased height and trunk diameter compared to single application
Warren and Bilderback, 2005	USA	Varied (review)	Increases water application efficiency 5-38% over single application

Table 3. Summaries of deficit irrigation effectiveness and findings as reported in reviewed articles.

Author(s)	Species/substrate	Efficacy/findings
Lamack and Niemiera, 1993	*Tagetes erecta* L. 'Apollo'/pine bark	Water application efficiency was 51% at 1200 ml medium moisture deficiency.
Welsh and Zajicek, 1993	*Photinia x fraseri* Dress/1:1:2 vermiculite, peat, bark	Growth maximized at 25% deficit irrigation; performance and water use suffered at >50% deficits.
Devitt et al., 1994	*Prosopsis alba* Grisebach, *Chilopsis linearis* (Cav.) Sweet var. *linearis, Quercus virginiana* Mill./75% blow sand, 25% forest litter-bark mix	Plants increased water use at higher leaching fractions; plant selection alone insufficient for water savings; water management practices needed.
Beeson, 2006	*Rhaphiolepsis indica* Lindl., *Viburnum odoratissimum* Ker Gawl, *Ligustrum japonicum* Thunb./64% pine bark, 24% sedge peat, 9% coarse sand	Drought tolerant species such as *Rhaphiolepsis indica* Lindl. can retain marketability with up to 80% water deficits; deficit results in increased production time
Warsaw and Fernandez, 2009	*Deutzia gracilis* Sieb. and Zucc *'Duncan', Kerria japonica* (L.)D.C. 'Albiflora', *Thuja plicata* D. Don 'Atrovirens', *Viburnum dentatum* L. 'Ralph Senior'/85% pine bark 15% peat moss	66% and 79% less operation runoff volume than control
Alvarez et al., 2013	*Pelargonium* x *hortorum* L.H. Baily/6:3:1 sphagnum peat, perlite, coconut fiber	Plants were shortest and had the least flowers when deficits were applied at flowering

Author(s)	Species/substrate	Efficacy/findings
Ahmed et al., 2014	*Capsicum annum* cv. Battle/1:1 sand, cotton stalk compost	Reduced growth, yield, and vitamin C content of fruit with deficit irrigation
Davies et al., 2016	*Cornus alba* L., *Lonicera periclymenum* Lour*., Forsythia x intermedia* Zabel/ pure peat and reduced peat (60% peat, 40% bark)	Deficit irrigation controlled growth utilizing overhead irrigation; reduced peat substrate plants demonstrated less growth.

Table 4. Summaries of CRF effectiveness and findings as reported in reviewed articles.

Author(s)	Species/substrate	Efficacy/findings
Boyle et al., 1991	*Rosmarinus officinalis* L./various	Combination of constant liquid feed and CRF produced plants with reduced shoot weight and plant height
Cox, 1993	*Tagetes erecta* L./2:1:1 sphagnum peat moss, pearlite, vermiculite	Early N losses when CRFs were applied in a single application were equal to or exceeded those seen from the use of soluble fertilizer applied via irrigation at the same annual rate
Broschat, 1995	*Tagetes erecta* L. 'Apollo'/pine bark	Water application efficiency was 51% at 1200 ml medium moisture deficiency.
Rathier and Frink, 1989	*Juniper horizontalis Moench* 'Plumosa Compacta Youngstown', *Picea glauca* Moench (Voss) 'Conica'/ 1:1:1 composted hardwood bark, sphagnum peat moss, sand	36% more leaching of NO_3-N than with drip irrigation when overhead irrigation was used
Godoy and Cole, 2000	*Spirea nipponica* Maxim./3:1:1 pine bark, peat, sand	CRFs can reduce the potential for contamination of surface water by decreasing the amount of nutrients in leachate
Bilderback, 2002	Varied	Drip or trickle irrigation can work in concert with CRFs to conserve water

Author(s)	Species/substrate	Efficacy/findings
Million et al., 2007	*Viburnum odoratissimum* (L.) Ker-Gawl. /2:1:1 aged pine bark, sphagnum peat moss, coarse sand	The most commonly found N form in leachate was NO_3-N
England et al., 2012	None (extension publication)	CRFs that do not release during production may release after the consumer purchases the plant, benefitting consumers

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Summary

Nursery and greenhouse growers use best management practices (BMPs) to increase production efficiency while reducing water and fertilizer use. These practices help prevent contamination of surface water and ultimately, the further impairment of protected waters such as those of the Chesapeake Bay. Growers commonly accept the premise that the implementation of BMPs increases production efficiency, although quantifying this has been elusive. Many growers implement BMPs on the assumption that publication in the BMP manual indicates such production practices has been proven to be effective, but prior to current research, growers were without a known efficiency or cost savings estimate to balance their original expenditures associated with BMP implementation. Meanwhile, growers face the pressures of regulatory actions associated with increasingly strict clean water goals.

Virginia's ornamental horticulture cash receipts are over $213 M (NASS, 2012), rendering Virginia a significant contributor to the Mid-Atlantic region's ornamental crop production. We conducted a survey of greenhouse and nursery operations in Virginia, with the goals of discovering the most widely used BMPs, reasons behind their use, and barriers to BMP adoption. We discovered that the most widely used BMPs included irrigation scheduling, integrated pest management (IPM), altering irrigation practices to optimize irrigation efficiency, plant need-based watering, grouping plants by water need, and the use of controlled-release fertilizer. Cost was the biggest barrier to BMP adoption. Environmental or resource savings was a frequently selected reason for growers to implement BMPs for water, fertilizer, and sediment

management. The most frequently selected reason for BMP implementation for fertilizer management was monetary, while the most frequently selected reasons for water and sediment management were water savings and environmental/resource savings. These findings suggest that environmental reasons support grower decisions in implementing BMPs.

Wider adoption of BMPs in the nursery and greenhouse operations is expected to help the industry address clean water goals through reductions in agriculture-related nonpoint source pollution. However, catalyzing an increase in BMP adoption requires more than just educating growers. Therefore, our survey also asked growers where they got their information pertaining to BMP adoption. Most frequently cited sources were seeing what others in the industry did, learning on their own, and cooperative extension. Therefore, to best reach growers and increase BMP use, we need to focus on those BMPs which are already in frequent use and provide information on their efficacy, since these are the BMPs that growers already see others in the industry using. Knowledge of the most widely used BMPs in the Virginia nursery and greenhouse industry gives cooperative extension personnel information on where to focus their efforts in increasing BMP use.

Starting with the most widely used BMPs, we can make BMPs more appealing to implement if we can provide scientific support of the efficacy of those BMPs. To provide this information, we investigated efficacies of selected BMPs frequently used by growers according to the survey, including grass buffer strips, irrigation optimization BMPs (plant needs-based water application, cyclic irrigation, and deficit irrigation), and controlled-release fertilizer. Through database searches, we found numerous articles supporting the effectiveness and use of these BMPs, demonstrating BMP efficacy in reducing nutrient and sediment runoff.

Growers are increasingly pressured to produce plants with less fertilizer and water. With this pressure, they will likely continue to use BMPs to reduce water and fertilizer waste and to increase production efficiency. Discovering the most frequently used BMPs, the reasons behind their use, and barriers to their adoption helps cooperative extension personnel to advise growers on BMP implementation, and assists growers in selecting BMPs the way they prefer: by observing which BMPs are being adopted by other growers. Linking the scientific evidence to the most widely used BMPs provides growers with confidence in using BMPs in their production operations, and gives information on efficacies that growers may expect to see in implementing these BMPs. This information assists growers in making decisions in BMP adoption for ultimately optimizing efficiency while reducing water and nutrient waste.

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Appendix A

Pilot Survey

SURVEY (for use for phone call or on-site visits)
The following survey should take about 5-10 minutes.

Is your operation primarily a nursery, greenhouse, or a mixed operation?

___

What is the approximate size of your operation?

___

Do you use BMPs?

___

If so, what BMPs do you use?

___

What has been your source of information for finding out about implementing BMPs? (BMP manual, learning on your own, sales representatives?)

___

This question asks about your gross sales, and will list a few categories (in dollars). Into which of these categories do your gross sales fall?

Up to $100,000
Up to $250,000
Up to $500,000
Up to $1,000,000
Up to $2,000,000
Up to $5,000,000
$10,000,000+

How do you apply fertilizer- liquid, CRF, or both?

___

How do you make fertilizer decisions?

___

What is your water source(s)?

How do you apply irrigation water-overhead, microirrigation, or both?

How do you schedule irrigation (plant need, set schedule, sensors)?

How do you move or manage on-site water to reduce sediment loss?

Do you collect and recycle your water?

How is the water managed or treated in the reservoir/collection pond?

What are the issues for your operation stemming from water management (for example, increased plant disease incidence, cost of collection/treatment/recycling?

Thank you very much for your time and cooperation!!!

For more information, contact:
Rachel Mack, rmack@vt.edu; or Dr. Jim Owen, jim.owen@vt.edu (757) 363-3904
Virginia Polytechnic Institute and State University

Appendix B

Main Survey

Best Management Practices Survey

Q This survey is being conducted by Dr. Jim Owen, Dr. Alex Niemiera, and Rachel Mack from the Department of Horticulture at Virginia Tech. The purpose of this study is to gather information on best management practices in the Virginia nursery/greenhouse industry, and to inform and improve growing practices in the state. Please complete this survey and be eligible for a drawing to win a Hanna pH/EC meter. Odds of winning a pH/EC meter depend on number of responses and are estimated to be about 1 in 63. The survey is expected to take about 10 minutes. The data from this survey will be used to help Virginia growers to make more informed nursery and greenhouse management decisions. Completing this survey constitutes consent for responses to be used for research, and results will be used for dissertation and publishing. Your personal information will be kept confidential.

*This survey asks about best management practices in Virginia nurseries and greenhouses. If your nursery or greenhouse has more than one production site in Virginia, please include all Virginia sites in your answers.

Best Management Practices Definition

Best Management Practices are methods or growing practices that can be used to reduce pollution, runoff, fertilizer use, water use, or other resource use or waste while making the most of nursery or greenhouse operation resources.

For example, a best management practice (BMP) may include using grass strips on a nursery's property to filter rainwater or irrigation runoff before the water leaves the property or reaches a water body.

Q Is your operation primarily a nursery, greenhouse, or mixed operation? Please answer the questions in this survey based on this operation type.

- ❍ Mostly nursery, some greenhouse (1)
- ❍ Mostly greenhouse, some nursery (2)
- ❍ Nursery only (3)
- ❍ Greenhouse only (4)
- ❍ 50/50 mixed operation of both nursery and greenhouse (5)

Q Is your business primarily located in Virginia?

- ❍ Yes (1)
- ❍ No (Please write in the box the state where your business is located.) (2) ____________________

Q Best management practices are methods or growing practices that can be used to reduce pollution, runoff, fertilizer use, water use, or other resource use or waste while making the most of nursery or greenhouse operation resources. Do you use best management practices (BMPs)?

- ❍ Yes (1)
- ❍ No (2)

Q If you DO NOT use BMPs, please explain why. (If you do not use BMPs, you may skip to the last survey page to provide your contact information for eligibility in the drawing) If you DO use BMPs, please continue with the next the question.

Q Please mark a rating for the following BMPs: 1= Strongly Disagree 10= Strongly Agree N/A= not applicable (the operation does not use the BMP) My nursery/greenhouse operation implements the following production or management practice(s):

	N/A	1- Strongly disagree	2	3	4	5	6	7	8	9	10- Strongly agree
On-site water capture and collection (1)	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Installation of grass strips (that filter water) (2)	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Irrigation scheduling (3)	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Installation of bioswale(s) see description in note below (4)	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Use of controlled - release fertilizers (5)	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
IPM (integrated pest management) (6)	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Optimized irrigation system efficiency (7)	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Plant need based water application (8)	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Grouping plants by water needs (9)	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
Irrigation via sensor	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑

control (10)											
Other (please specify) (11)	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑

* a bioswale is a depressed area of land filled with vegetation, compost, or riprap, and designed to manage the movement of surface runoff water while removing pollutants and silt.

Q About how many acres is your nursery/greenhouse operation?

Q Why do you use BMPs in irrigation management (check all that apply)?
❑ Saves time (1)
❑ Saves money (2)
❑ Compliance with law(s)/concern about regulatory violation (3)
❑ Saves water or other resources (4)
❑ Environmental stewardship (5)
❑ Efficiency/business/production reasons (6)
❑ I don't use these BMPs (7)
❑ Other (please specify) (8) ____________________

Q Why do you use BMPs in fertilizer management (check all that apply)?
❑ Saves time (1)
❑ Saves money (2)
❑ Compliance with law(s)/concern about regulatory violation (3)
❑ Saves water or other resources (4)
❑ Environmental stewardship (5)
❑ Efficiency/business/production reasons (6)
❑ I don't use these BMPs (7)
❑ Other (please specify) (8) ____________________

Q Why do you use BMPs in runoff management (check all that apply)?
❑ Saves time (1)
❑ Saves money (2)
❑ Compliance with law(s)/concern about regulatory violation (3)
❑ Saves water or other resources (4)
❑ Environmental stewardship (5)
❑ Efficiency/business/production reasons (6)
❑ I don't use these BMPs (7)
❑ Other (please specify) (8) ____________________

Q Has anything stopped you from adopting a BMP or BMPs?
- ❍ Yes (1)
- ❍ No (2)

Q If you answered yes to the previous question, please check what stopped you from adopting BMPs (check all that apply).
- ❑ Cost (1)
- ❑ Upgrades needed first (2)
- ❑ Lacked equipment (3)
- ❑ Lacked knowledge (4)
- ❑ Not enough time (5)
- ❑ Other (please specify) (6) ____________________
- ❑ N/A (7)

Q How would you rate the impact of implementing BMPs on your cost savings?
- ❍ Minor (1)
- ❍ Moderate (2)
- ❍ Major (3)

Q How would you rate the impact of implementing BMPs on your environmental impact?
- ❍ Minor (1)
- ❍ Moderate (2)
- ❍ Major (3)

Q What has been your source of information for finding out about implementing BMPs (check all that apply)?
- ❑ Extension (publications, personnel) (1)
- ❑ BMP manual (2)
- ❑ Vendors (3)
- ❑ Learning on own (4)
- ❑ Seeing what other industry members did (5)
- ❑ Other (6) ____________________

Q How do you apply fertilizer: liquid, controlled-release fertilizer (CRF), or both (choose all that apply)? Reminder: please respond based on the primary function of your operation (nursery, greenhouse or mixed operation)
- ❑ Mainly liquid, some CRF (1)
- ❑ Mainly CRF, some liquid (2)
- ❑ Only CRF (3)
- ❑ Only liquid (4)
- ❑ 50/50 of each liquid and CRF (5)

Q How do you make fertilizer application decisions (check all that apply)?
❑ Testing substrate or substrate solution (ex., pour-through technique) (1)
❑ Plant appearance/need (2)
❑ Fertilizer label (3)
❑ Cost effectiveness (4)

Q What is your primary water source?
❍ On-site pond/stream/lake (1)
❍ Well (2)
❍ Off-site river/stream/lake (3)
❍ Other (4) ____________________

Q How do you apply irrigation?
❍ Mostly overhead (1)
❍ Mostly microirrigation (drip or spray stakes) (2)
❍ Mostly boom (6)
❍ about 50/50 overhead/microirrigation (7)
❍ about 50/50 microirrigation/boom (8)
❍ about 50/50 overhead/boom (9)

Q How do you schedule irrigation for the primary portion of your operation (check all that apply)?
❑ Grower determined/experience (1)
❑ Set time or amount (2)
❑ Sensor/weather based model (3)
❑ Other (please specify) (4) ____________________

Q Are you concerned with sediment loss (soil leaving the operation/growing area)?
❍ Yes (1) ____________________
❍ No (2) ____________________

Q If you answered yes to the previous question, how do you manage on-site sediment (skip to next question if not concerned with sediment loss)?

Q What are the top 3 most important issues you are concerned about regarding water management at your operation?

Q Thank you for completing this survey! To be eligible for the pH/EC meter drawing, please provide your contact email and mailing address. Your information will be kept confidential.

Q Email

Q Mailing address

Appendix C

IRB Documents

Phone contact script

SCRIPT:

My name is Rachel Mack and I am a graduate student at Virginia Tech conducting an in-person survey of Virginia growers. Do you have 60 seconds to listen to an explanation of my survey? (If not: when may I call back?) The survey is to benefit the nursery/greenhouse industry; the focus of this survey is best management practices (BMPs). Your contact information was obtained through faculty/friends of Virginia Tech's horticulture department. Best management practices are activities, procedures, or schedules of management used by growers to maximize use of resources (for example, water, fertilizer, pesticides) and to reduce or prevent pollutant discharge into the air or water. For example, BMPs can include the use of controlled release fertilizers, or the use of grass filter strips to filter irrigation runoff.

Interviews will assist in developing a written survey. The ultimate goal is to better position the nursery/greenhouse industry in the eyes of regulatory agencies. All information gained in this survey will not be linked to your operation. Will you agree to a 15-20 minute in-person visit? If not, can you do the survey by phone? (If so, a consent document needs mailed to you for your signature. Where should it be sent? When may I call back?)

Survey Information Sheet

This survey is to benefit the nursery/greenhouse industry; the focus of this survey is best management practices (BMPs). Your contact information was obtained through faculty/friends of Virginia Tech's horticulture department. Best management practices are activities, procedures, or schedules of management used by growers to maximize use of resources (for example, water, fertilizer, pesticides) and to reduce or prevent pollutant discharge into the air or water. For example, BMPs can include the use of controlled release fertilizers, or the use of grass filter strips to filter irrigation runoff. We want to anonymously share these practices with the Chesapeake Bay Program to 1) identify practices being utilized by Virginia growers, (2) demonstrate the science behind selected practices, (3) demonstrate that the nursery and greenhouse industries are on the forefront of environmental stewardship and4) to use these BMPs to minimize government regulations 6on growers by asking for inclusion in Chesapeake Bay Program BMPs.

Form letter

Dear ________

I am a graduate student working with Drs. Jim Owen and Alex Niemiera at Virginia Tech on a project to benefit the Virginia nursery/greenhouse industry. The project will demonstrate the environmental stewardship by the nursery/greenhouse industry through the utilization of best management practices (BMPs) commonly employed by growers.

I am conducting a survey of current practices to cost effectively manage water and nutrients. I would like to meet with a knowledgeable person for approximately 30-60 minutes from your nursery the week of XXXXXX. Alternatively, I could conduct a phone interview the week of XXXXXX. If available, please let me know how would like to participate and what days are open that week for a visit or call.

Thank you for your time.

Respectfully,

Rachel Mack

Graduate Student, Virginia Tech Horticulture

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed Consent for Participants
in Research Project Involving Human Subjects

Title of Project: Determining Utilization and Efficacy of Best Management Practices for the Virginia Nursery and Greenhouse Industry

Investigator(s):	**Dr. Jim Owen (PI)**	**jim.owen@vt.edu**
	Name	E-mail / Phone number
	Dr. Alex Niemiera (Co-PI)	**niemiera@vt.edu**
	Name	E-mail / Phone number
	Rachel Mack (Graduate student)	**rmack@vt.edu**
	Name	E-mail / Phone number

I. Purpose of this Research Project

The survey is to benefit the nursery/greenhouse industry; the focus of this survey is best management practices (BMPs). Best management practices are activities, procedures, or schedules of management used by growers to maximize use of resources (i.e. water, fertilizer, pesticides) and reduce or prevent pollutant discharge into the air or water. For example, BMPs can include the use of controlled release fertilizers, or the use of grass filter strips to filter irrigation runoff. We want to anonymously share these practices with the Chesapeake Bay Program to 1) identify practices being utilized by Virginia growers, (2) demonstrate the science behind selected practices, (3) demonstrate that the nursery and greenhouse industries are on the forefront of environmental stewardship and4) to use these BMPs to minimize government regulations on growers by asking for inclusion in Chesapeake Bay Program BMPs. Results of the study may be used for publication and/or dissertation, but your identifying information will be kept confidential. Photos taken on nursery or greenhouse sites may be used for research publication, but no identifying information will be used with the pictures. A total of between 5-15 nursery and greenhouse crop growers of varying ages will be interviewed.

II. Procedures

Should you agree to participate, you will be asked via email or phone to participate in a survey. The survey may be completed one of two ways: as a phone survey read to you by an investigator, or as an in-person interview conducted at the nursery or greenhouse operation site or an alternative site. The phone interviews are expected to take about 5-10 minutes to complete, and in-person interviews are expected to take 15-20 minutes. The interview/phone survey will be conducted one time per participating nursery or greenhouse crop grower selected during summer or Fall 2015. In-person interviews may include taking photos of the interview location.

III. Risks

All identifying information will be kept confidential. Photos used for publication of any kind will not include names or identifying information.

IV. Benefits

Benefits of the study include the use of the study data to demonstrate that the nursery and greenhouse industries are on the forefront of environmental stewardship and to use BMPs to minimize government regulations on growers by asking for inclusion in Chesapeake Bay Program BMPs. No promise or guarantee of benefits has been made to encourage you to participate.

V. Extent of Anonymity and Confidentiality

Codes will be assigned to each participant. Identifying information, such as names and email addresses, will be kept separately from the data and will be stored on a password protected computer. Results will not include identifying information, but will include the use of the codes in place of the identifying information. Access to identifiable and/or de-identified data will be restricted to individuals working on the project. At no time will the researchers release identifiable results of the study to anyone other than individuals working on the project without your written consent. The Virginia Tech (VT) Institutional Review Board (IRB) may view the study's data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

VI. Compensation

No compensation is to be earned for this study.

VII. Freedom to Withdraw

It is important for you to know that you are free to withdraw from this study at any time without penalty. You are free not to answer any questions that you choose or respond to what is being asked of you without penalty.

Please note that there may be circumstances under which the investigator may determine that a subject should not continue as a subject.

Should you withdraw or otherwise discontinue participation, you will be compensated for the portion of the project completed in accordance with the Compensation section of this document.

VIII. Questions or Concerns

Should you have any questions about this study, you may contact one of the research investigators whose contact information is included at the beginning of this document.

Should you have any questions or concerns about the study's conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact the VT IRB Chair, Dr. David M. Moore at moored@vt.edu or (540) 231-4991.

IX. Subject's Consent

I have read the Consent Form and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ Date__________
Subject signature

____
Subject printed name

(Note: each subject must be provided a copy of this form. In addition, the IRB office may stamp its approval on the consent document(s) you submit and return the stamped version to you for use in consenting subjects; therefore, ensure each consent document you submit is ready to be read and signed by subjects.)

Phone invitation

Good morning/afternoon/evening. You have been selected to receive an invitation to participate in a study being conducted by Dr. Jim Owen, Dr. Alex Niemiera, and Rachel Mack from the Department of Horticulture at Virginia Tech. The purpose of this study is to gather information on best management practices in the Virginia nursery/greenhouse industry, and to inform and improve growing practices in the state. Your contact information was obtained through faculty/friends of Virginia Tech's horticulture department. The study contains a survey. The survey is most accurate if completed by the person at your operation who is the most knowledgeable of best management practices.

The survey is estimated to take about 10 minutes, and participation is confidential and anonymous. Survey participants will have a chance to win a Hanna pH/EC meter. The odds of winning are estimated at about 1 in 63. Results of this survey will be used for dissertation and publishing. Would you be willing to participate?

If so, investigator reads the entire survey, including the consent information at the top of the survey, from the following link to the participant:
https://virginiatech.qualtrics.com/SE/?SID=SV_bluy7kmaT2RMtYp

If not willing to participate, simply thank potential participant for their time.

Invitation letter

Dear XXXXXX,

You have been selected to receive an invitation to participate in a study being conducted by Dr. Jim Owen, Dr. Alex Niemiera, and Rachel Mack from the Department of Horticulture at Virginia Tech. The purpose of this study is to gather information on best management practices in the Virginia nursery/greenhouse industry, and to inform and improve growing practices in the state. Your contact information was obtained through faculty/friends of Virginia Tech's horticulture department. The study contains a survey. The survey is most accurate if completed by the person at your operation who is the most knowledgeable of best management practices.

The survey is estimated to take about 10 minutes, and participation is confidential and anonymous. Survey participants will have a chance to win a Hanna pH/EC meter. The odds of winning are estimated at about 1 in 63. Results of this survey will be used for dissertation and publishing. If you are willing to participate, please complete the survey at the link below:
https://virginiatech.qualtrics.com/SE/?SID=SV_bluy7kmaT2RMtYp

Alternatively, you may complete the enclosed paper survey and return it to:

Rachel Mack
Virginia Tech/Dept. of Horticulture (0327)
404 Saunders Hall
490 W. Campus Drive
Blacksburg, VA 24061

Best Regards,

Rachel Mack

Graduate Student, Virginia Tech Horticulture

Invitation email

Good morning/afternoon/evening. You have been selected to receive an invitation to participate in a study being conducted by Dr. Jim Owen, Dr. Alex Niemiera, and Rachel Mack from the Department of Horticulture at Virginia Tech. The purpose of this study is to gather information on best management practices in the Virginia nursery/greenhouse industry, and to inform and improve growing practices in the state. Your contact information was obtained through faculty/friends of Virginia Tech's horticulture department. The study contains a survey. The survey is most accurate if completed by the person at your operation who is the most knowledgeable of best management practices.

The survey is estimated to take about 10 minutes, and participation is confidential and anonymous. Survey participants will have a chance to win a Hanna pH/EC meter. The odds of winning are estimated at about 1 in 63. Results of this survey will be used for dissertation and publishing. If you are willing to participate, please complete the survey at the link below:
https://virginiatech.qualtrics.com/SE/?SID=SV_bluy7kmaT2RMtYp

(To be included if deemed necessary): Alternatively, you may print the attached copy of the survey and return it to:

Rachel Mack
Virginia Tech/Dept. of Horticulture (0327)
404 Saunders Hall
490 W. Campus Drive
Blacksburg, VA 24061

Best Regards,

Rachel Mack

Graduate Student, Virginia Tech Horticulture