Workshop: Clean WateR^3: Reduce, Remediate, Recycle—Using Transdisciplinary Science to Help Specialty Crop Producers Conserve Water and Resources

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Access to high-quality irrigation water is increasingly limited for specialty crop production. Given the production, environmental, and economic issues associated with the use of lower quality, alternative (e.g., recycled) water sources, researchers from 10 institutions worked on a Coordinated Agriculture Project sponsored by the National Institute of Food and Agriculture, U.S. Department of Agriculture—through the Specialty Crops Research Initiative. Over the last 4 years, the Clean WateR^3 project team has developed new science-based information resources that greenhouse and nursery growers can use to more efficiently use and manage water in their operations. Integration of research expertise from socioeconomic, environmental/ecological engineering, biological/horticultural systems, plant pathology, and environmental toxicology disciplines enabled the Clean WateR^3 team to holistically address grower concerns and integrate a variety of data into systems-based solutions growers can use to more efficiently manage water. A portion of the results from this project were presented at the 2018 ASHS meeting in Washington, DC, in three special sessions and are further detailed in the eight articles in this series.

The objectives of the three special sessions were to 1) provide perspectives related to water use by nursery and greenhouse producers and information on how to facilitate grower decision making; 2) detail various practices and treatment technologies that can help to manage nutrient, pesticide, and disease contaminants in water growers use for irrigation; and 3) show how outreach practices influence grower access to and use of research-based information. Each session was focused on an objective, with 13 presentations delivered over 3 d.

Special session I: Clean WateR^3—the big picture, why clean water matters

Sarah White introduced the three sessions with "Clean WateR^3 for specialty crop production: Past, present, and future," providing an overview of the Clean WateR^3 project that briefly discussed the guidance received from growers who completed surveys and participated in round-table discussion sessions that helped formulate project goals and objectives, and then detailed the technologies and tools the research and extension team developed to help growers *reduce* inputs of water and agrichemical in their operations, *remediate* agrichemical and plant pathogen contaminants from production runoff with the ultimate goal of increasing adoption of water *recycling* practices at specialty crop facilities. Charlie Hall discussed "The economics of water use" by detailing both the economic engineering approach used to estimate the production costs and initial capital investment for both current (baseline) and potential (change in practice) irrigation models and the partial budgeting technique used to compare the added costs of changing practice with the cost savings associated with that same change in practice. Jennifer Parke discussed "Phytopathogens, nursery plant production and water" by presenting four case studies that detailed the locations and types of phytopathogens within each operation, and the steps growers needed to take to identify potential sources of contamination and corrective steps to prevent diseases from infecting plants.

Special session II: Clean WateR^3—big picture outreach

Bruno Pitton opened the session by presenting "Comparing the cost of high-quality and recycled irrigation runoff water in container plant production: A southern California nursery case study," detailing the considerable cost savings associated with the use of recycled water in comparison with high-cost municipal water, despite the high initial infrastructure investment costs (Pitton et al., 2018). John Majsztrik presented "Tools for growers to assess disease risk," discussing the web-based tool growers can use to identify situations or practices that are most likely to spread plant pathogens at their operation and provide a hazard assessment related to current practice and potential corrective actions. Erin Yafuso presented "Coordinating water quality outreach to best reach your audience," discussing how both the use of social media and traditional outreach avenues (e.g., biweekly newsletters with research updates, webinars, workshops, and the project website (University of Florida, 2019) that hosts interactive tools tailored for grower use) served to enhance interactions with growers. Dewayne Ingram presented "Water security and life cycle assessment – impact of water recycling," detailing how life cycle assessment can be used to systematically evaluate the relative environmental impacts of current production practices on a producer's global warming

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potential (carbon footprint) and water consumption (water footprint) (Ingram and Hall, 2015; Ingram et al., 2017; Knight et al., 2019).

Special session III: Clean WateR³—reduce, remediate, recycle

Jim Owen opened the session by presenting "Rate of phosphorus needed to grow seven ornamental taxa and subsequent fate within the container system," detailing efforts to determine how much phosphorus (P) is required by plants so that fertilization recommendations can be modified below the currently recommended 5-mg·L^{-1} (ppm) rate. Owen also discussed the effect of substrate amendments (e.g., lime and micronutrients) on the fate of P in containers. Tom Fernandez presented "Reducing water and pesticide movement in nursery production," detailing dynamic water and pesticide management strategies to reduce the movement of both water and pesticides in irrigation runoff. Andrew Ristvey presented the "Effect of plant available water reduction on two yellow garden mum cultivars," detailing how reducing substrate moisture availability influenced the growth and flowering of two chrysanthemum (*Chrysanthemum morifolium*) cultivars. Cassandra Swett presented "Irrigation practices and pathogen infection potential: Balancing reduced water use with oomycete disease risk in containerized nursery production," detailing the potential for effectively comanaging oomycete pathogens and water use by strategically reducing soil moisture at later plant developmental stages. Loren Oki presented "Slow sand filters are effective in removing water-borne plant pathogens from captured irrigation runoff," detailing the efficacy of slow sand filters to remove inoculum of both species of *Phytophthora* and tobacco mosaic virus from infested runoff water. Lauren Garcia Chance and Natasha Bell presented "Nutrient and pathogen remediation using floating treatment wetlands," detailing plant screening studies conducted with floating treatment wetlands to document the efficacy of nutrient uptake by various plant species and reductions in the presence of *Phytophthora* species in simulated irrigation runoff after exposure to plants in floating treatment wetlands.

The eight articles in this series expand the body of information available to growers, researchers, and extension professionals related to efficient use of water and agrichemicals, contaminant management (pesticide, nutrient, and plant pathogen), the water footprint of plant producers, and opportunities to enhance adoption of water treatment practices. Some of the information resources developed include technologies that can help growers 1) increase water use efficiency and reduce pesticide movement (Abdi and Fernandez, 2019; Poudyal et al., 2019), 2) select effective management practices (Mack et al., 2019), 3) remove contaminants from irrigation runoff (Garcia Chance et al., 2019; Ridge et al., 2019), and 4) understand critical control points for mitigating disease and pesticide movement at grower production facilities (Parke et al., 2019; Ridge et al., 2019). Additional socioeconomic information resources were developed to help research and extension professionals understand how water use (application, consumption, and footprint) changes by region and operation (Knight et al., 2019) and how to identify opportunities to present information to stakeholders to encourage adoption and continued use of underused treatment technologies or practices (Lamm et al., 2019).

These eight articles coupled with the recorded ASHS presentations serve to advance our understanding of the economics, engineering, chemistry, and biology of water, its use, and reuse. Additional information is provided on how we can better frame information sharing (extension) practices via grower-centric web design (University of Florida, 2019), social media, biweekly newsletters, webinars, and workshops to increase technology adoption. Integration of research outputs from both laboratory/field sciences and social/behavioral sciences is helping to enhance the economic and environmental sustainability of water use by specialty crop producers across the United States.

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