Recycling Irrigation Water on Ornamental Nursery Operations: Could Consumer Premiums Compensate for Grower Adoption Costs?

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Abstract. The U.S. nursery and greenhouse industry is facing twin challenges of reduced water availability and increased pressure to mitigate pollution from horticultural production. Water-recycling technology (WRT) has been adopted by some nursery producers to improve crop water productivity and to enhance water supply security. This study estimated the economic feasibility of WRT adoption if producers received some portion of retail price premiums for eco-labeled products. Three annual bedding plants, Geraniums (Pelargonium spp.), Petunias (Petunia spp.), and Chrysanthemums (Chrysanthemum spp.) and three broadleaf evergreen plants, Azaleas (Rhododendron spp.), Holly (Ilex spp.), and Boxwood (Buxus spp.) were analyzed based on their sales in the study region of Virginia (VA), Maryland (MD), and Pennsylvania (PA). Of the eight case study nurseries and two synthesized nurseries examined, five showed increased net costs with recycling. However, in almost all cases for which at least a portion of a retail consumer premium was returned to growers, the premium was adequate to compensate for recycling investment costs.

Productivity of irrigation water use and contaminant runoff control are becoming increasingly important to nursery and greenhouse growers as well as to policymakers and the public. Increased attention to minimizing total applications of water to obtain a healthy plant (water use productivity) is prompted by water scarcity in U.S. regions such as the West as well as by environmental concerns about agricultural runoff. Concern for water quality in the Chesapeake Bay and its tributaries led the U.S. Environmental Protection Agency (USEPA, 2010) to issue a Total Maximum Daily Load plan for reducing nitrogen, phosphorus, and sediment runoff in the Chesapeake Bay watershed. Under increasing pressure to adopt solutions to address regulatory and drought concerns, some nurseries have adopted WRT, which involves capturing and recycling irrigation water to improve crop water productivity and to enhance water supply security while reducing contaminants lost from nursery and greenhouse production sites. It is estimated that a 0.4 ha (1-acre) greenhouse producing ornamental crops requires 83,270 L (22,000 gallons) daily for irrigation, and container nursery operations may require up to 102,195 L (27,000 gallons) daily (Bailey et al., 1999; Robbins, 2010). With WRT, it is estimated that 40% to 50% of water applied could be conserved through recapture and reuse of both irrigation water and any storm water runoff (Wilson and von Broembsen, n.d.), thus increasing security of water supplies and reducing pollutant loads to nearby surface waters. Ferraro et al. (2017) provided detailed analysis of recycling requirements and costs for VA, MD, and PA nurseries.

Long-term access to secure irrigation water supply is of critical importance to nursery growers. WRT also can potentially provide social benefits by reducing discharge to streams and rivers of polluted water from horticultural operations. In some cases, the increased risk of water-borne plant pathogens spreading through recycled water has impeded WRT adoption and associated social benefits from reduced water pollution (Hong and Moorman, 2005; von Broembsen, 1998). In addition, the concern about production cost increases associated with WRT, and the uncertainty of revenue enhancement discourage many growers from implementing the new technology (Cultice et al., 2016).

Many retail customers of horticultural products are concerned about environmental degradation and are now more aware of environmental aspects of production. Previous research has indicated that consumers are willing to pay premiums for plants produced and labeled as “environmentally friendly” or “eco-friendly” (Behe et al., 2014; Gardner et al., 2002; Michaud et al., 2012; Yue et al., 2010). Plants grown with WRT qualify for such a designation because WRT reduces discharge of polluted water. For example, consumers are willing to pay more for “eco-labeled” roses certifying eco-friendly cultivation practices (Michaud et al., 2012). Eco-labeling of environmentally friendly or “green” products has gained interest because environmental practices are highlighted (e.g., using recycled water). Consumers receive more information about the product, and new market opportunities and potential higher profits may be generated. In addition, contract farming has become more common in the U.S. horticulture industry (MacDonald, 2015). Contracting producers and wholesale purchasers such as landscapers or retailers such as “big-box” stores should share price premiums obtained from consumers with contracting producers as financial incentives to promote adoption of conservation practices such as WRT. Little research has been conducted as to how such price premiums might be transmitted through stages of the distribution system from consumers back to growers, or how such premiums relate to costs incurred by growers to produce such eco-labeled attributes. In this case, nursery growers find it hard to obtain useful economic information about the profit potential of WRT and its anticipated effect on their business’ long-term bottom line.

Will consumer premiums for plants grown with recycled water be sufficient to make WRT economically practical? This analysis evaluates the economic effects of labeling plants grown with WRT in selected nursery operations in the mid-Atlantic region of VA, MD, and PA. The goal is to estimate the economic feasibility of WRT production practices, which include capturing and recycling rainfall and irrigation runoff, combined with plant eco-labeling, and to determine how such a program would affect greenhouse/nursery production costs, gross revenues, and net revenues. Research results can help nursery growers and policymakers assess WRT adoption to improve crop water productivity and to reduce pollution of off-site surface waters.

Literature Review

Driven by increased awareness of the need for environmental protection, green products have become more popular among consumers in both food and non-food marketing systems. A so-called “green” product usually refers to a product produced with methods that improve environmental quality or reduce environmental pollution compared with an equivalent product produced with conventional practices (Durif et al., 2010). For example, plants grown with WRT could be considered “green” because recycling water may reduce discharge of polluted water...
to rivers and streams. Schlegelmilch et al. (1996) illustrated that consumer environmental-consciousness has positive effects on their purchasing decisions for green products. Larocie et al. (2001) investigated the profile of consumers willing to pay more for green products generally including their demographics, attitudes toward environmentally friendly programs, daily behavior, and personal values. They found this segment of consumers was more likely to be female, married, and with at least one child living at home.

Horticultural products provide both private and public benefits for consumers. Private product benefits are limited to the buyer, whereas public benefits are available to the buyer as well as others. For example, if a horticultural product is produced in a manner that reduces or eliminates pollutants, the product presents a public benefit. Consumers cannot readily evaluate some public benefits such as reduced pollution unless these attributes are communicated via product labeling. Research has found that consumers prefer and are willing to pay a price premium for horticultural products that promise environmental benefits (Behe et al., 2013, 2014; Gardner et al., 2002; Harter, 2012; Khachatryan et al., 2014; Michaud et al., 2012; Yue et al., 2010, 2016). Gardner et al. (2002) used the contingent valuation method to estimate that consumers were willing to pay a retail premium of as much as $13.35 for a flowering dogwood tree labeled as “resistant to powdery mildew.” Using hypothetical conjoint analysis and non-hypothetical experimental auctions, Yue et al. (2010) found that consumers were willing to pay premiums for plants grown in biodegradable vs. plastic containers. Michaud et al. (2012) found that consumers were willing to pay an average premium of €1.91 ($2.56) per stem for roses claiming “resistant to powdery mildew.” Using hypothetical conjoint analysis and non-hypothetical experimental auctions, Yue et al. (2010) found that consumers were willing to pay an average premium of €2.51 ($3.36) per stem for roses claiming a carbon footprint reduction. Harter (2012) conducted a choice experiment to estimate the premiums that consumers would be willing to pay for ornamental plants produced with WRT and labeled as “water conservation.” The author found that, on average, retail consumers were willing to pay 9% to 36% more than the average retail price for Geranium, Petunia, Chrysanthemum, Azalea, Holly, and Boxwood. Behe et al. (2013) profiled nine consumer segments in terms of their preferences for local and sustainably grown plant products.

More recently, a subsequent article by Behe et al. (2014) used eye-tracking technology to categorize three plant consumer groups as plant-oriented, production method-oriented, and price-oriented. The authors found that regardless of their groups, all consumers preferred ornamental plants labeled “grown using water-saving practices” over other production labels such as “grown using energy-saving practices,” “grown using sustainable practices,” and “grown using conventional practices.” The results also indicated that 11% of the respondents were production method-oriented among which water-saving label increased their Likert willingness to pay (WTP) scale by ≈6.5%. Khachatryan et al. (2014) performed a mixed-logit model to estimate consumers’ premiums for environmental attributes of horticulture plants, finding that individuals were willing to pay a premium for energy-saving production practices ($0.13), non-plastic containers such as compostable ($0.23), plantable ($0.12), and recyclable ($0.16), and locally grown plants ($0.22). Yue et al. (2016) investigated the U.S. consumers’ WTP for sustainable attributes in plants via experimental auctions. The results showed that consumers were willing to pay a price premium for water savings in plant production of $0.15 and $0.12 per unit, respectively, and the WTP for products labeled “sustainable” was estimated at $0.08 per unit. These previous studies indicate that consumers are willing to pay premiums for the underlying environmental attributes of a product that promises societal benefits.

However, product labels do not completely define a product, especially in terms of environmental attributes. Usually, certifications conveyed to consumers by product labeling confirm environmental attributes. Previous research has found that consumers prefer to pay more for certified vs. uncertified products and that they generally prefer third-party certification to first party or self-certification (Aguilar and Vlaskoy, 2007; Curtis and Cowee, 2010; Harter, 2012; Michaud et al., 2012). Harter (2012) assumed three categories of third-party certification authorities for water conservation including governmental organizations, industry organizations, and nongovernmental organizations (NGO). Specifically, the U.S. Department of Agriculture represented the governmental organization; the American Nursery Association (a fictitious certifying agency) represented an industry-backed agency; and Water for Tomorrow and Plant Society of America represented a fictitious NGO for water conservation certification. The estimation results indicate that consumers have varying preferences for WTPs for plants certified by different authorities.

On the producer side of markets, studies of WRT adoption by horticultural growers are limited. Cultice (2013) conducted a mail survey of mid-Atlantic irrigated nursery producers to determine irrigation practices and used a conditional logit model to estimate the impacts of disease probability, drought probability, and water-recycling cost on producers’ WTP to adopt water-recycling techniques and practices. Of 260 irrigated nurseries, 55% reported that they did not capture any irrigation runoff; and only 14% captured all irrigation runoff (Cultice et al., 2016). Only six irrigated nurseries (2.3%) sourced all their irrigation water from municipal or private well sources. They found that six of eight case nurseries (all of whom had already adopted some WRT practices) had lower production costs from capturing and recycling on 75% of their production areas compared with using well or municipal water.

Materials and Methods

In this study, budgets from Ferraro et al. (2017) provide the basis for assessing producer costs of capturing and recycling. Calibrated consumer premium results are taken from Hartter (2012) as the prices that consumers would be willing to pay for plants grown with WRT. These premiums allow us to compare non-water-recycling practices (e.g., grower net returns sourcing irrigation water from municipal or private well sources) vs. returns from WRT. With adoption of WRT, changes in production costs including water-supply cost, labeling cost, and certification cost are compared with benefits from price premiums for plants labeled as “irrigation water recycled,” and varying proportions are assumed to be returned to growers as compensation for the WRT investment. Hinson et al. (2012) studied market channels of ornamental plant industry and concluded that mass merchandisers have sufficient market power to affect grower prices and profitability. Retailers (e.g., “big-box” stores) could use their market power to mandate grower WRT practices while retaining some of or the entire premium for themselves. We reflect this uncertainty by varying the proportion of the premium returned to the grower (R) as was done by White et al. (2014) in a study of consumer premiums for sustainable beef-production practices.

We conducted the study with eight case nurseries varying in terms of size, location, and water supply method. The eight case nurseries include three in VA (VA-1, VA-2, and VA-3), three in MD (MD-1, MD-2, and MD-3) and two in PA (PA-1 and PA-2). All eight operations are adopters of WRT as they capture rainfall and irrigation runoff in collection basins and then recycle the water to supplement water supply in addition to using municipal city water or well water. Nurseries
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MD = Maryland; PA = Pennsylvania; VA = Virginia.

SynLarge 36.0 100% well water
PA-2 10.9 100% recycling
MD-2 42.5 100% recycling
VA-2 40.5 100% recycling

Table 1. Size and water source of the eight case study nursery operations and two simulated nurseries.

| Nursery | Hectares | Current water supply method |
|---------|----------|----------------------------|
| VA-1    | 1.0      | 34% recycling, 66% well    |
| VA-2    | 40.5     | 100% recycling             |
| VA-3    | 80.9     | 100% recycling             |
| MD-1    | 6.7      | 50% recycling, 50% well    |
| MD-2    | 42.5     | 100% recycling             |
| MD-3    | 22.3     | 100% recycling             |
| PA-1    | 2.0      | 100% recycling             |
| PA-2    | 10.9     | 100% recycling             |
| SynSmall| 36.0     | 100% well water            |
| SynLarge| 10.2     | 100% recycling             |

Data source: Ferraro et al. (2017).
MD = Maryland; PA = Pennsylvania; VA = Virginia.

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Table 2. Sales and percent of total U.S. sales of six horticultural plants by state in 2014.

| Nursery Plant | VA | MD | PA | VA | MD | PA | VA | MD | PA |
|---------------|----|----|----|----|----|----|----|----|----|
| Geranium      | 6,773 | 1,112 | 5,585 | 6,253 | 1,594 | 1,077 | 7,204 | N/A | 2,485 |
| Petunia       | 6.0% | 1.0% | 4.9% | 9.8% | 2.5% | 1.7% | 15.2% | N/A | 5.3% |
| Chrysanthemum | 584 | 326 | 3,185 | 260 | 200 | 857 | 47 | N/A | 207 |

Note: The percentage number placed under each sale volume represents each state’s share of U.S. Retail/Wholesale/Total sales for each type of the six plants.

Data source: U.S. Department of Agriculture, National Agricultural Statistics Service (2014).

MD = Maryland; PA = Pennsylvania; VA = Virginia.

Table 3. Net water supply cost changes for eight nursery operations (VA-1 to PA-2) and two simulated nurseries (SynSmall and SynLarge) with alternative water sources.

| Nursery Alternative | More profitable option | WRT cost ($/ha) | Alternative cost ($/ha) | Water supply cost change with WRT ($/ha) |
|---------------------|------------------------|-----------------|-------------------------|---------------------------------------|
| VA-1                | Municipal water        | WRT             | 4,400                   | 6,024                                 |
| VA-2                | Municipal water        | WRT             | 4,817                   | 34,728                                |
| VA-3                | Municipal water        | WRT             | 5,874                   | 12,213                                |
| MD-1                | Well water             | WRT             | 650                     | 1,463                                 |
| MD-2                | Municipal water        | WRT             | 3,770                   | 6,621                                 |
| MD-3                | Well water             | WRT             | 7,923                   | 406                                   |
| PA-1                | Well water             | WRT             | 26,967                  | 27,310                                |
| PA-2                | Municipal water        | Municipal water | 4,242                   | 2,044                                 |
| SynSmall            | Well water             | Well water      | 5,956                   | 2,146                                 |
| SynLarge            | Well water             | Well water      | 9,035                   | 1,384                                 |

Data source: Ferraro et al. (2017).

MD = Maryland; PA = Pennsylvania; VA = Virginia; WRT = Water-recycling technology.

certification systems to define production with recycled irrigation water. It is assumed that producers who wish to increase net returns with recycling would contract a qualified and respected third party to certify that their operations and nursery products accord with specific standards of WRT. Such standards would specify minimum requirements as to how water is recycled to ensure that the environmental benefits of recycling are achieved. After certification, producers are authorized to label plants as “produced with recycled water,” whereby consumers can acquire environmental information that may influence their preferences and WTP for horticultural products.

Labeling cost and certification costs also relate to the documentation of cost changes in water-supply practices resulting from recycling. Based on the information provided by the owners and managers of the case nurseries during on-site interviews, the unit labeling cost is about $0.10/pot. Thus, a labeling cost change is

$$\Delta L C_i = 0.1 \cdot Y_i,$$  \[4\]

where $\Delta L C_i$ is the labeling cost change, and $\Delta Y_i$ is the net negative change of normal production per hectare for recyclers specified in Eq. [1]. The labeling cost associated with WRT in Eq. [4] is negative because of the yield loss from increased plant death rate.

The example cost data for certification is developed from the “Sustainability Standard for Nursery and Greenhouse Operations” operated by Food Alliance, a nonprofit organization that has certified over 330 farms, ranches, and food processors in Canada, Mexico, and 23 U.S. states for good environmental stewardship. Although the organization does not have an independent certification program focusing on water recycling for the nursery industry, the sustainability standard does contain specific criteria for water conservation and recycled water quality in nursery operations. The Food Alliance publishes detailed certification costs on its website that are used in this analysis. The certification costs consist of an inspection fee and a license fee. The inspection fee includes a nonrefundable $350 document processing charge and a $400 deposit toward the actual cost of inspection. According to Food Alliance, in most cases, the average inspection fee is between $900 and $1500. Because Food Alliance certification is valid for 3 years, the average annual inspection fee ranges from $300 to $500 per year. In addition, nursery operations pay a variable annual license fee based on a percentage of gross annual sales ($100 flat fee less than $100,000, 0.10% from $100,000 to $1,000,000, and 0.05% greater than $1,000,000), with a licensing fee cap of $5000. For example, gross revenue for nursery MD-2 reported in the survey is $7,000,000; thus, the annual license fee would be $3500. After adding the maximum average annual inspection fee of $500, the average annual certification cost would be $94/ha ($94/ha[$350 + $500]/42.5 ha). Errors in estimating certification costs are unlikely to affect final results because in three-fourths of the cases (Tables 4–7), the certification cost is 3% or less of the total production cost change.

For this analysis, it is assumed that in a typical wholesale nursery production contract, retailers offer price premiums to encourage contract growers to produce plants with WRT. Following Cultice (2013), ≈52% of growers are wholesalers. Thus, a conservative assumption in this analysis is that the case nurseries are wholesalers who sell all plants directly to retailers, who in turn sell to consumers and return a portion of the premium to growers. If growers were retailers, they would retain all of the premium. Equation [5] clarifies how price premiums tied to WRT plants could be returned proportionally to growers and increase gross revenue.

$$\Delta G R_i = GR_{iWRT} - GR_{iNon-WRT} = \left(100\% - 3\%\right)P_{iWRT}^{WTR} - \left(100\% - 2\%\right)P_{iNon-WRT}^{WTR} = 0.97 \cdot P_{iWTR}^{WTR} - 0.98 Y_i \cdot P_{iWTR}^{WTR} = \Delta Y_i \cdot P_{iWTR}^{WTR} + 0.97 \cdot Y_i \cdot WTP \cdot R$$  \[5\]

where $P_{iWTR}^{WTR}$ is the new wholesale price after adding a proportional premium (denoted as WTP), in which $R$ is a conveyance rate indicating the fraction of
the consumer premium being returned to the water-recycling nursery. After readjusting, \( \Delta Y_{r, P} \) refers to the gross revenue loss from WRT because of yield loss, whereas 0.97 \( \frac{1}{\gamma} \) \( \delta \) \( WTP_{r} \) is the increased gross revenue resulting from consumer premiums for plants grown with WRT.

Premium estimates obtained from growers by Hartter (2012) are based on survey responses to a hypothetical choice experiment. However, hypothetical responses may suffer from “hypothetical bias,” i.e., overstating consumer WTP compared with revealed choices of consumers with actual purchases in non-hypothetical situations (Blumenschein et al., 2008; Cummings et al., 1995; Harrison, 2006; Harrison and Rutström, 2008; List and Gallet, 2001; Silva et al., 2007; Yue et al., 2010). For example, List and Gallet (2001) summarized 29 experimental studies and concluded that respondents on average overestimated their preferences by a factor of 3 in hypothetical settings compared with actual purchases. Silva et al. (2007) found that on average, the non-hypothetical estimates of WTP estimates for different groups of novel

| Table 4. Labeling cost changes (\( \Delta LC \)), certification cost changes (\( \Delta CC \)), and production cost changes (\( \Delta PC \)) with water recycling technology for Geranium. |
| --- |
| Plant type | Nursery | Labeling cost change ($/ha) | Certification cost change ($/ha) | Water-supply cost change ($/ha) | Production cost change ($/ha) |
| --- | --- | --- | --- | --- | --- |
| Geranium (10.2 cm pot) | VA-1 | -69 | 593 | -1,624 | -1,446 |
| | VA-2 | -69 | 136 | -29,910 | -30,189 |
| | VA-3 | -69 | 67 | -6,339 | -6,687 |
| | MD-1 | -69 | 300 | -813 | -929 |
| | MD-2 | -69 | 94 | -2,851 | -3,172 |
| | MD-3 | -69 | 56 | 7,516 | 7,157 |
| | PA-1 | -69 | 988 | -343 | 230 |
| | PA-2 | -69 | 62 | 2,199 | 1,845 |
| | SynSmall | -69 | 110 | 3,810 | 3,504 |
| | SynLarge | -69 | 42 | 7,651 | 7,278 |

| MD = Maryland; PA = Pennsylvania; VA = Virginia. |

| Table 5. Labeling cost changes (\( \Delta LC \)), certification cost changes (\( \Delta CC \)), and production cost changes (\( \Delta PC \)) with water recycling technology for Petunia. |
| --- |
| Plant type | Nursery | Labeling cost change ($/ha) | Certification cost change ($/ha) | Water-supply cost change ($/ha) | Production cost change ($/ha) |
| --- | --- | --- | --- | --- | --- |
| Petunia (6 packs) | VA-1 | -69 | 593 | -1,624 | -1,100 |
| | VA-2 | -69 | 136 | -29,910 | -29,843 |
| | VA-3 | -69 | 67 | -6,339 | -6,341 |
| | MD-1 | -69 | 300 | -813 | -583 |
| | MD-2 | -69 | 94 | -2,851 | -2,826 |
| | MD-3 | -69 | 56 | 7,516 | 7,503 |
| | PA-1 | -69 | 988 | -343 | 576 |
| | PA-2 | -69 | 62 | 2,199 | 2,191 |
| | SynSmall | -69 | 110 | 3,810 | 3,850 |
| | SynLarge | -69 | 42 | 7,651 | 7,624 |

| MD = Maryland; PA = Pennsylvania; VA = Virginia. |

| Table 6. Labeling cost changes (\( \Delta LC \)), certification cost changes (\( \Delta CC \)), and production cost changes (\( \Delta PC \)) with water recycling technology for Chrysanthemum, Azalea, and Boxwood. |
| --- |
| Plant type | Nursery | Labeling cost change ($/ha) | Certification cost change ($/ha) | Water-supply cost change ($/ha) | Production cost change ($/ha) |
| --- | --- | --- | --- | --- | --- |
| Chrysanthemum; Azalea; Boxwood (3.8 L pot) | VA-1 | -52 | 593 | -1,624 | -1,083 |
| | VA-2 | -52 | 136 | -29,910 | -29,826 |
| | VA-3 | -52 | 67 | -6,339 | -6,324 |
| | MD-1 | -52 | 300 | -813 | -566 |
| | MD-2 | -52 | 94 | -2,851 | -2,809 |
| | MD-3 | -52 | 56 | 7,516 | 7,521 |
| | PA-1 | -52 | 988 | -343 | 594 |
| | PA-2 | -52 | 62 | 2,199 | 2,208 |
| | SynSmall | -52 | 110 | 3,810 | 3,868 |
| | SynLarge | -52 | 42 | 7,651 | 7,641 |

| MD = Maryland; PA = Pennsylvania; VA = Virginia. |

| Table 7. Labeling cost change (\( \Delta LC \)), certification cost change (\( \Delta CC \)), and production cost changes (\( \Delta PC \)) with water recycling technology for Holly. |
| --- |
| Plant type | Nursery | Labeling cost change ($/ha) | Certification cost change ($/ha) | Water-supply cost change ($/ha) | Production cost change ($/ha) |
| --- | --- | --- | --- | --- | --- |
| Holly (7.6 L pot) | VA-1 | -26 | 593 | -1,624 | -1,057 |
| | VA-2 | -26 | 136 | -29,910 | -29,800 |
| | VA-3 | -26 | 67 | -6,339 | -6,298 |
| | MD-1 | -26 | 300 | -813 | -540 |
| | MD-2 | -26 | 94 | -2,851 | -2,783 |
| | MD-3 | -26 | 56 | 7,516 | 7,546 |
| | PA-1 | -26 | 988 | -343 | 619 |
| | PA-2 | -26 | 62 | 2,199 | 2,234 |
| | SynSmall | -26 | 110 | 3,810 | 3,894 |
| | SynLarge | -26 | 42 | 7,651 | 7,667 |

| MD = Maryland; PA = Pennsylvania; VA = Virginia. |
products were from 8% to 29% lower than the hypothetical WTP estimates in two elicitation mechanisms including experimental auction and conjoint analysis. Blumenschein et al. (2008) concluded that the average WTP for a pharmacist-provided diabetes program in a real purchasing group was 50% lower than that obtained in hypothetical surveys. Yue et al. (2010) found that the mean WTP for plant containers made from rice hulls (straw) obtained from an experimental auction was 29% (39%) lower than that obtained from a hypothetical conjoint analysis. Although Hartter (2012) applied a “cheap talk” method as suggested by Cummings and Taylor (1999) to reduce hypothetical bias and the potential for artificially high WTP estimates, premium estimates are calibrated (divided by 3) as suggested by List and Gallet (2001).

The horticultural plant price data $P_{w}^{i}$ (wholesale) and $P_{r}^{i}$ (retail) is obtained from the Census of Horticultural Specialties (USDA/NASS, 2014). The calibrated (divided by 3) mean values of estimated premiums by Hartter (2012) are shown with 2014 census prices in Tables 8 and 9 after adjustment to 2014 dollars using the consumer price index of indoor plants and flowers (U.S. Bureau of Labor Statistics, 2015).

Finally, the net revenue change from recycling (ANR$_{i}$) is the difference between gross revenue change and production cost change:

$$\Delta NR_{i} = \Delta GR_{i} - \Delta PC_{i}$$

where $\Delta GR_{i}$ is the gross revenue change calculated with Eq. [5] and $\Delta PC_{i}$ is the production cost change calculated with Eq. [3].

The sensitivity of gross and net revenue changes to the conveyance rate (R) is evaluated with the premium estimate fixed at its mean value. Three possible R values are selected: 0%, $P_{w}^{i}/P_{r}^{i}$, and 100%. Zero percent is a pessimistic value at which the grower receives nothing from the consumer premiums; $P_{w}^{i}/P_{r}^{i}$ is the census price ratio of wholesale price and retail price of each plant in Tables 8 and 9; and 100% is an optimistic value at which the grower receives the complete premium. Where price ratios $P_{w}^{i}/P_{r}^{i}$ exceed 100%, such as Azalea in PA, Holly in MD, and Boxwood in VA and MD, 100% is used. In addition, break-even analyses to balance production cost and gross revenue change associated with WRT (i.e., $\Delta NR_{i} = 0$) are conducted in terms of conveyance rate R, premium estimate and plant death rate.

**Results**

**Production cost changes.** Labeling cost changes, certification cost changes and production cost changes resulting from WRT are presented in Tables 4–7. For each of the six plants, nurseries VA-1, VA-2, VA-3, MD-1, and MD-2 have lower production costs with WRT compared with well water or municipal water as the reduced labeling cost and water supply cost more than offset the certification cost in each case. For nurseries MD-3, PA-1, and PA-2 and for the two simulated nurseries SynSmall and SynLarge, the production costs of WRT are higher than using well water or municipal water. Production costs increase for MD-3, PA-2, SynSmall, and SynLarge because of large water supply cost increases ranging from $2199 to $7651 per hectare. WRT reduces water supply costs for PA-1; however, production costs increase modestly because of the certification cost ($988/ha/year). The high certification cost for PA-1 is mainly because of its reported high per hectare gross revenue (= $241,915/ha), much higher than other nurseries.

**Gross revenue changes with WRT.** Table 10 shows the estimated changes in gross revenues by plant species with alternative conveyance rates. Y$_{i}$ and $Y_{i}^{'}$ are held constant for all nurseries, therefore, changes of gross revenues resulting from different wholesale prices garnered by each nursery operation are based on its geographic location. SynSmall and SynLarge are assumed located in MD, so their gross revenue changes match those of MD case nurseries. When no premiums go back to growers (conveyance rate $R = 0\%$), all nurseries have negative gross revenue changes for each of the six plants because of the assumed increased plant death rate with WRT. When the conveyance rate is 100% (growers obtain all premium) and when $R = P_{w}^{i}/P_{r}^{i}$, all 10 nurseries have positive changes in gross revenue for five plants with Holly as an exception. For Holly, the nurseries in VA have decreased gross revenues at –$1098/ha when $R = P_{w}^{i}/P_{r}^{i}$ or $R = 100\%$.

**Net revenue changes with WRT.** After deducting production cost changes from the gross revenue changes, the net revenue changes for alternative conveyance rates are shown in Tables 11 and 12. In the cases of Azalea in PA, Holly in MD, and Boxwood in VA and MD, the wholesale price ($P_{w}^{i}$) is greater than the retail price ($P_{r}^{i}$) reported in the Census as shown in Tables 8 and 9. In those cases, $P_{w}^{i}$ is assumed equal to $P_{r}^{i}$ resulting in the same gross revenue change as obtained for $R = 100\%$.

When the conveyance rate $R$ is 0%, only nursery VA-2 has increased net revenue for all plants because of its large production cost saving from WRT that fully offsets the opportunity cost of yield loss. For nursery VA-1, only Petunia generates a positive net revenue change of $291/ha. Nursery VA-3 has increased net revenues for all plants except Geranium (–$1034/ha) and Chrysanthemum ($157/ha)
Table 10. Gross revenue sensitivity ($\Delta GR$) to conveyance rates ($R$).

| Nursery type | Syn (Small, Large) | PA (1, 2) | MD (1, 2, 3) | VA (1, 2, 3) |
|--------------|--------------------|----------|-------------|-------------|
|              | –2,652             | –1,930   | –2,652      | –1,863      |
|              | 20,503             | 12,997   | 20,503      | 12,274      |
|              | –13,310            | –8,640   | –13,310     | –12,885     |
|              | 17,059             | 13,155   | 17,059      | 17,484      |

Note: The two simulated nurseries are assumed located in MD, thus the results for Syn (Small, Large) and MD (1, 2, 3) are always equal in this table. MD = Maryland; PA = Pennsylvania; VA = Virginia.

Table 11. Net revenue sensitivity ($\Delta NR$) to conveyance rates ($R$) for three annual bedding plants.

| Nursery | R = 0% | R = $P_W^e / P_T^e$ | R = 100% |
|---------|--------|---------------------|----------|
| VA-1    | –6,275 | 137,582             | 201,777  |
| VA-2    | 22,468 | 166,326             | 230,520  |
| VA-3    | –1,034 | 142,824             | 207,018  |
| MD-1    | –7,623 | 119,443             | 200,430  |
| MD-2    | –5,380 | 118,490             | 202,673  |
| MD-3    | –15,709| 108,160             | 198,776  |
| PA-1    | –7,661 | 119,443             | 200,391  |
| PA-2    | –9,276 | 117,828             | 198,776  |
| SynSmall | –12,056| 111,813             | 195,996  |
| SynLgge | –15,830| 108,040             | 192,223  |

R = 0 = 0% indicates that growers should be returned to balance the –$6275/ha net revenue change associated with WRT for Geranium; whereas R = 100% shows the break-even premiums are $0.50/pot or $1.00/kg.

Table 12. Net revenue sensitivity ($\Delta NR$) to conveyance rates ($R$) for three broadleaf evergreen plants.

| Nursery | R = 0% | R = $P_W^e / P_T^e$ | R = 100% |
|---------|--------|---------------------|----------|
| VA-1    | –3,562 | 12,131              | 18,250   |
| VA-2    | 25,182 | 40,875              | 54,699   |
| VA-3    | –1,680 | 17,372              | 23,492   |
| MD-1    | –5,137 | 6,771               | 16,675   |
| MD-2    | –2,894 | 9,014               | 18,918   |
| MD-3    | –13,223| –1,315              | 8,588    |
| PA-1    | –10,406| 11,406              | 11,406   |
| PA-2    | –12,021| 9,791               | 9,791    |
| SynSmall | –9,571 | 2,338               | 12,241   |
| SynLgge | –13,344| –1,436              | 8,468    |

R = 0 = 0% indicates that growers should be returned to balance the –$6275/ha net revenue change associated with WRT for Geranium; whereas R = 100% shows the break-even premiums are $0.50/pot or $1.00/kg.

The remaining nurseries (MD-1, MD-3, PA-1, PA-2, SynSmall, and SynLgge) have negative net revenue changes for all plants when R = 0%.

When R = $P_W^e / P_T^e$, MD-3 and SynLgge have decreased net revenue for Azalea, estimated at –$1315/ha and –$1436/ha, respectively. VA-1, MD-1, PA-1, PA-2, SynSmall, and SynLgge have negative changes for Holly, estimated at –$41/ha, –$7765/ha, –$406/ha, –$2021/ha, –$2042/ha, and –$8886/ha, respectively.

Except for three cases (Holly on MD-3, SynSmall, and SynLgge), all 10 nurseries gain more net revenues for all plants from WRT when the conveyance rate R = 100% than well water or municipal water. Net revenue increase because the returned premiums generate larger gross revenues to offset the opportunity costs of yield losses as well as the increased production costs with WRT.

Break-even conveyance rate R. For those nurseries that suffer from decreased net revenues associated with WRT for different plants as shown in Tables 11 and 12, the corresponding break-even conveyance rates and production cost changes ($\Delta NR = 0$) are shown in Table 13. For example, for nursery VA-1, a small break-even conveyance rate R = 3.0% will balance the –$6275/ha net revenue change associated with WRT for Geranium; whereas for nursery PA-2, a large break-even R = 98.3% offsets the –$8327/ha net revenue change related to WRT for Holly. With only three exceptions (Holly on nursery MD-3, SynSmall, and SynLgge), break-even conveyance rates are less than 100% as shown in Table 13, indicating that growers could cover WRT costs with a sufficient share of consumer premiums.

Break-even premium results. Table 14 shows the break-even premiums corresponding to the break-even R shown in Table 13 that should be returned to growers to balance net revenue. Overall, with only two exceptions (Holly in nursery MD-3 and SynLgge), the break-even premiums are $0.50/pot or $1.00/kg.
less for all plants and all nurseries. Specifically, the break-even premiums for the three annual bedding plants are well below $0.20/pot on average, and are more consistent with previous findings such as Yue et al. (2016), whereas the break-even premiums for the three broad leaf evergreen are slightly higher than previous findings.

Break-even death rate results. The death rate after adoption of WRT is assumed to be nondecreasing based on survey responses reported in Culrice (2013). However, pathogen mitigation practices (Hong and Moorman, 2005) might reduce plant disease incidence below the level obtained without WRT. Reducing plant disease incidence might provide another way to offset additional costs associated with WRT even without returned premiums. Table 15 shows the break-even death rates required to offset the added WRT production costs of nurseries MD-3, PA-1, PA-2, SynSmall, and SynLarge if no premiums are assumed to be returned to producers (\( R = 0\% \)). These five nurseries are highlighted because they show an increase in production cost with recycling (Tables 4–7). The results illustrate that for most cases, reducing death rates below 2\% increase the assumed average rate for non-recycling nurseries, can offset the additional cost incurred from conversion to WRT even without returned premiums. However, there are six exceptions (e.g., Petunia for MD-3) where the death rate would need to be reduced by more than 2\% to offset increased production cost with recycling. A greater than 2\% reduction leads to a physically impossible negative death rate. For these exceptions, reducing plant disease incidence fails to completely offset the added WRT production costs.

Discussion

Public desire to improve water quality poses environmental challenges for the horticulture industry as demonstrated by policies that require conservation measures. The nursery industry continues to face challenges of reduced product sales resulting from the downturn in the housing market in 2009, although it has partly recovered in recent years. At the same time, the industry faces increasing competition for scarce water supplies in some regions. This study concludes that consumer premiums for plants grown with recycled water could offer nursery growers a method to improve their net returns while addressing environmental challenges and improving irrigation crop water productivity.

Adoption of WRT offers some nurseries the opportunity to reduce water supply costs relative to well water or municipal water. In addition, consumer premiums that could be obtained from plants grown with WRT could outweigh increased production costs of WRT as well as possible economic losses.

Table 13. Break-even conveyance rate \( R \) required to balance gross revenue and production cost changes (\( \Delta NR = 0 \)).

| Nursery | Geranium (%) | Petunia (%) | Chrysanthemum (%) | Azalea (%) | Holly (%) | Boxwood (%) |
|---------|--------------|-------------|-------------------|------------|-----------|-------------|
| VA-1    | 3.0          | N/A         | 3.4               | 16.3       | 28.9      | 38.9        |
| VA-2    | N/A          | N/A         | N/A               | N/A        | N/A       | N/A         |
| VA-3    | 0.5          | N/A         | N/A               | N/A        | N/A       | 21.6        |
| MD-1    | 3.7          | 1.5         | 9.0               | 23.6       | 96.2      | 42.0        |
| MD-2    | 2.6          | N/A         | 13.3              | 69.7       | 34.6      | 68.6        |
| MD-3    | 7.6          | 37.7        | 43.9              | 191.6      | 68.6      | 30.4        |
| PA-1    | 3.7          | 6.3         | 10.9              | 47.7       | 79.2      | 30.4        |
| PA-2    | 4.5          | 13.5        | 17.9              | 55.1       | 98.3      | 35.7        |
| SynSmall| 5.8          | 21.4        | 28.2              | 43.9       | 148.5     | 56.6        |
| SynLarge| 7.6          | 38.2        | 44.5              | 193.1      | 69.0      |             |

Note: N/A refers to the case where break-even analysis is not applicable because the net revenue change is already positive without any premium returned as shown in Tables 11 and 12.

Break-even rates greater than 100\% indicate that the estimated consumer premium is not adequate to cover production cost changes. MD = Maryland; PA = Pennsylvania; VA = Virginia.

Table 14. Break-even premiums corresponding to the break-even \( R \) required to balance gross revenue and production cost changes (\( \Delta NR = 0 \)).

| Nursery | Geranium ($/pot) | Petunia ($/pot) | Chrysanthemum ($/pot) | Azalea ($/pot) | Holly ($/pot) | Boxwood ($/pot) |
|---------|-----------------|-----------------|-----------------------|---------------|--------------|----------------|
| VA-1    | 0.02            | N/A             | 0.02                  | 0.07          | 0.10         | 0.23           |
| VA-2    | N/A             | N/A             | N/A                   | N/A           | N/A          | N/A            |
| VA-3    | 0.003           | N/A             | 0.04                  | 0.10          | 0.32         | 0.25           |
| MD-1    | 0.02            | 0.01            | 0.04                  | 0.10          | 0.32         | 0.25           |
| MD-2    | 0.01            | N/A             | 0.06                  | 0.23          |              | 0.21           |
| MD-3    | 0.04            | 0.13            | 0.20                  | 0.26          | 0.65         | 0.41           |
| PA-1    | 0.02            | 0.02            | 0.05                  | 0.21          | 0.27         | 0.18           |
| PA-2    | 0.02            | 0.05            | 0.08                  | 0.24          | 0.33         | 0.22           |
| SynS    | 0.03            | 0.07            | 0.13                  | 0.19          | 0.50         | 0.34           |
| Syn-L   | 0.04            | 0.13            | 0.20                  | 0.27          | 0.65         | 0.42           |

Note: N/A refers to the case where break-even analysis is not applicable because the net revenue change is already positive without any premium returned as shown in Tables 11 and 12.

MD = Maryland; PA = Pennsylvania; Syn-S = SynSmall; Syn-L = SynLarge; VA = Virginia.

Table 15. Break-even death rate to offset added water recycling technology production costs of nurseries MD-3, PA-1, PA-2, SynSmall, and SynLarge when conveyance rate \( R = 0\% \).

| Nursery | Geranium (%) | Petunia (%) | Chrysanthemum (%) | Azalea (%) | Holly (%) | Boxwood (%) |
|---------|--------------|-------------|-------------------|------------|-----------|-------------|
| MD-3    | 1.2          | N/A         | N/A               | 0.7        | 1.1       | 1.4         |
| PA-1    | 2.0          | 1.3         | 1.7               | 1.9        | 1.9       | 1.9         |
| PA-2    | 1.8          | N/A         | 0.9               | 1.8        | 1.6       | 1.7         |
| SynSmall| 1.6          | N/A         | 0.5               | 1.3        | 1.6       | 1.7         |
| SynLarge| 1.1          | N/A         | N/A               | 0.7        | 1.1       | 1.4         |

Note: For some plants, death rates would have to be negative for break-even between recycling and not recycling without any premiums returned. Because negative death rates are impossible, such cases are labeled N/A.

MD = Maryland; PA = Pennsylvania; VA = Virginia.
associated with increased plant disease risk. Additional production costs of WRT could also be lowered by reducing plant death rate below levels that occur without WRT (Table 15). Therefore, treatment of recycled water with effective pathogen mitigation procedures should always be considered as suggested by Hong and Moorman (2005).

Nursery growers have diverse production operations and management practices, which depend on location, state and federal policies, market channel, and other considerations. For some nurseries, physical layout restricts the adoption of WRT. For example, limited land on some small farms or flower farms will deter some nurseries from regrading or digging ponds for recycled water, making it impossible to implement WRT regardless of public or private incentives.

Although consumer premiums have potential to make WRT economically feasible for many growers, the logistical resources needed to establish a labeling program for WRT may be beyond the capability of a single horticultural firm. A centralized government or industry organization may be best suited to lead the implementation of certification and labeling of plants grown with WRT. In this case, the “green washing” for WRT practices imposed by sellers, i.e., the act of misleading consumers via promising more environmental benefits of the product than they actually deliver can be effectively mitigated through well-established industry standards and certification programs.

The results of this analysis are specific to only eight case nurseries and two simulated nurseries in mid-Atlantic states. These results should be replicated with a larger set of nurseries and in alternate climate zones. Further analysis could also focus on the upfront costs facing growers who wish to transition to WRT and the length of time required to pay back these costs with alternative recycling premiums. Investments in water-saving technology (e.g., precision watering) provide an alternate way of reducing water use and should be evaluated as well. Research should consider the potential for scale economies when evaluating such investments. The premiums estimated by Hartter (2012) were based on hypothetical questions instead of actual marketing experiments. Better estimation of consumer premiums should be possible through experiments involving actual consumer purchases (Chang et al., 2009; Hudson et al., 2012). Additional experiments involving actual consumer purchases would allow for an evaluation of the feasibility of implementing WRT.

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