Understanding Greenhouse Growers' Willingness to Use Municipal Recycled Water on Food Crops: The Need for Tailored Outreach Coupled with Deep Engagement to Increase Adoption

Chesney McOmber[1], Christine J. Kirchhoff[2], Yan Zhuang[3], and Rosa E. Raudales[4]

Keywords. barriers to adoption, engagement, extension, grower perceptions, recycled water

Abstract. **Increasing demand on agricultural water resources have caused a greater need for the use of municipal recycled wastewater (MRW) globally. However, in the United States, greenhouse growers have been slow to use it in their greenhouse operations. In this study, we seek to understand the factors that motivate and limit use of MRW among US growers. Using national survey data from 2019 through 2020, we developed a logistic regression model to understand the many factors influencing growers' willingness to use MRW on food crops. We find that MRW quality is a primary concern and that growers' willingness to use MRW is shaped by their direct and indirect knowledge of MRW, garnered from their own and others' experiences using it. Given these findings, improving adoption of MRW requires collective experiential learning opportunities that gather target audiences with educators, policymakers, end users, and local authorities to simultaneously provide hands-on experience tailored to growers' particular knowledge and concerns with feedback from peers.**

There is a growing need for water conservation, particularly in agriculture, where increased demand for irrigation, coupled with climate change, threatens global water supplies (Mekonnen and Hoekstra 2016; Suri et al. 2019). In the United States, agricultural production is responsible for 80% of annual water use (Bixio et al. 2006; Fulcher et al. 2016; Savchenko et al. 2019). Agricultural producers—including greenhouse growers—have expressed concern about water availability (White et al. 2019) and although access to safe alternative water sources, such as recycled water, has increased (Cultice et al. 2016; Yeager et al. 2010), their widespread adoption has not occurred. In this study, we aimed to understand what motivates greenhouse growers to adopt and use municipal recycled wastewater (MRW) in their greenhouse operations and what barriers prevent it.

Greenhouse growers hold largely negative perceptions about alternative water sources, including MRW, because of concerns about its safety (Cultice et al. 2016; Dery et al. 2019; McOmber et al. 2021). Growers are also concerned about consumer attitudes toward agricultural products irrigated with recycled water (Savchenko et al. 2018, 2019). Trust in the safety of recycled water and in the authorities responsible for ensuring recycled water quality can also undermine use (Po et al. 2003). At the same time, US growers have little experience with and knowledge about recycled water (McOmber et al. 2021), which is thought to impede use (Dery et al. 2019; Lamm et al. 2019; McOmber et al. 2021). Although scholarship in this area provides some clues regarding the barriers to growers' recycled water use, studies often treat growers as a homogenous group, which misses the underlying heterogeneity in grower understanding, perceptions, and willingness to use recycled water (McOmber et al. 2021).

Rather than general education, growers need tailored information and outreach that can address their diverse interests, problem-solving styles, and knowledge levels with regard to recycled water use in their greenhouse operations. Nursery and greenhouse growers' problem-solving style affects how they perceive water conservation technologies and, hence, its adoption (Warner et al. 2020). Growers are influenced to implement and adopt water conservation technologies based on the characteristics that provide information about the relative advantage, trialability, and observability of technologies (Warner et al. 2020) or the grower's knowledge level (Warner et al. 2018). The failure to understand grower heterogeneity in knowledge or problem-solving style—among other characteristics—means that we lack critical knowledge necessary to provide tailored information and approaches that can address and overcome growers' particular concerns that discourage their recycled water use. Recommendations to provide education and outreach about recycled water to growers must also reflect the nuances of diverse grower interests so that information can be made useful in decisions regarding recycled water use (Dery et al. 2019; Lamm et al. 2017; White et al. 2019). Moreover, when generalized approaches are used to research and support growers, they often fail to address the range of other factors that motivate or discourage growers' recycled water

Received for publication 23 Sep 2022. Accepted for publication 20 Dec 2022.

Published online 27 Jan 2023.

[1]Department of Civil and Environmental Engineering, University of Connecticut, 261 Glenbrook Road, Unit 3037, Storrs, CT 06269, USA

[2]School of Engineering Design and Innovation, The Pennsylvania State University, 213 Hammond Building, University Park, PA 16802, USA

[3]Department of Mathematics and Statistics, Connecticut College, 270 Mohegan Avenue, New London, CT 06320, USA

[4]Department of Plant Science and Landscape Architecture, University of Connecticut, 1376 Storrs Road, Unit 4067, Storrs, CT 06269, USA

This work is supported by Agriculture and Food Research Initiative Water for Agriculture grant no. 2017-69007-26311/project accession no. 1011821 from the US Department of Agriculture, National Institute of Food and Agriculture. The funders had no role study design, data collection and interpretation, or the decision to submit the work for publication.

Institutional review board approval was obtained by the University of Connecticut (Protocol X18-112).

C.J.K. is the corresponding author. E-mail: cxk475@psu.edu.

https://doi.org/10.21273/HORTTECH05132-22

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.0929	ft^2	m^2	10.7639

use, including socioeconomic (Cultice et al. 2016) and environmental concerns (Dery et al. 2019).

With this research, we seek to better understand diversity among growers and how it is reflected in what motivates and limits growers' MRW use. In this article, we draw from survey data we collected from 2019 to 2020 on growers' knowledge, perceptions, and willingness to use MRW. We use a logistic regression model to explore the effect of several factors—including concerns over water quality, trust in regulatory institutions, consumer trust, knowledge and experience, capital and monetary incentives, and environmental concerns—on growers' willingness to use MRW. Our results help shed light on the factors that seem to influence a growers' willingness to use MRW and how they may inform approaches to outreach and education, including tailoring such approaches to different informational needs and motivations of growers. We close with a discussion on the implications of these findings and the insights they offer for improving the willingness to use recycled water among growers in the United States.

Knowledge gaps and promising avenues to improve recycled water use

Past scholarship has largely argued that greenhouse growers lack information about recycled water and that filling this knowledge gap would enable recycled water use; more recent research suggests that a more nuanced consideration of diverse informational needs is critical. For example, White et al. (2019) found that growers desired more information about costs, availability, treatment, and quality of alternative water sources such as recycled water to make informed decisions about implementing different kinds of water conservation methods within their greenhouse operation. White et al. (2019) argued that having more information about costs would help growers understand how much capital investment is required to replace irrigation system piping to enable use of MRW. In other studies of US growers' knowledge and perceptions of alternative water sources, scholars found that growers lacked knowledge about recycled water treatment (Dery et al. 2019; Lamm et al. 2019). Each of these studies concludes that providing growers with technical and financial information about recycled water, thus filling knowledge gaps among growers, may help to improve its uptake (Dery et al. 2019; Lamm et al. 2019). Yet emerging research suggests that informational needs are far from uniform across all growers (McOmber et al. 2021).

Recent work has begun to unpack the heterogeneity of growers' understandings about what recycled water is and how their perceptions shape its suitability for use. For example, McOmber et al. (2021) found growers' definitions of recycled water differ from those of scholars and policymakers. Growers' varied thinking about recycled water means most growers do not think of recycled water as treated municipal wastewater (hereafter, MRW), and most growers do not understand how MRW is produced (McOmber et al. 2021). Indeed, Lamm et al. (2019) found that most growers know little about the processes involved in recycling water on the farm. This lack of understanding about how water is recycled suggests that many growers may also misunderstand the processes involved and the quality of MRW and its overall suitability for greenhouse production. Consequently, growers appear to hold largely negative perceptions about alternative water sources. These negative perceptions stem from growers' concerns about pathogen contamination and the risk of disease from alternative water sources, such as reclaimed or recirculated water (Cultice et al. 2016; Dery et al. 2019). Helping growers gain a better understanding of the treatment processes involved in producing recycled water can help growers become more amenable to its use (Lamm et al. 2019; McOmber et al. 2021; Wilson and von Broembsen 2017). Countering such negative perceptions likely requires more intensive and tailored approaches.

Experience and deep engagement between water authorities or agricultural extension and growers appear to counter negative perceptions about recycled water quality that impede use. For example, studies show that when target audiences are included as active participants in committees, working groups, and workshops around water, there is improved acceptance of new water-focused technology and policy (Scott et al. 2021). These approaches may work well for agricultural producers who often resist new technology (Kenny and Regan 2021; Maertens and Barrett 2012). "Deep engagement" refers to the process of "developing lasting relationships with practitioners … and leveraging science in ways that help to advance practitioners' agendas" (Williams and Whiteman 2021, p 527). In their study on the Monterey County Recycling Project, Po et al. (2003) found that deep engagement with growers over time, through ongoing iterations of safety tests and procedures, increased trust in the safety of MRW and in the authorities responsible for ensuring MRW quality in the region.

While experience, tailored education, and engagement may help overcome misunderstandings and negative perceptions of MRW among greenhouse growers, other factors may impede growers' use of recycled water. For example, environmental concerns about water scarcity have been linked with growers' willingness to use recycled water. Dery et al. (2019) found a link between elderly growers' experience with stressed water resources due to low availability and their acceptance of water reuse. The lack of technical capacity or lack of access to a source of MRW may also limit uptake (McOmber et al. 2021). Funding may be another challenge. Cultice et al. (2016) found that greenhouse operations with gross annual revenues under $25,000 were less likely to adopt MRW. Among these low-revenue greenhouse operations, real or perceived costs of implementation may be a barrier to use (White et al. 2019). Monetary incentives (with education) may help overcome costs of implementation and improve adoption of recycled water (Cultice et al. 2016).

The preceding literature demonstrates the many factors influencing a willingness to use alternative water sources, including recycled water. In what follows, we present a methodology for understanding whether and how these factors—trust, knowledge, perceptions, environmental concerns, and economic factors—independently and collectively influence greenhouse growers' willingness to use MRW. More specifically, we try to answer two main questions: 1) In what ways are trust, knowledge, perceptions, environmental concerns, and economic factors respectively related to greenhouse growers' willingness to use MRW on food crops? 2) What are the determining factors for willingness to use MRW on food crops? Findings

from our analysis may help inform a broader range of interventions among greenhouse growers to improve their recycled water use.

Methods

This section details the survey used for data collection, the representativeness of our survey data, and approaches for data preparation. We then present the statistical methods used to analyze survey results, including exploratory data analysis, chi-square test of independence, and logistic regression.

Survey, sampling, and data preparation. We developed a survey (McOmber et al. 2021) and pilot tested it among 12 greenhouse growers, which were excluded from the final sample. A revised survey was distributed through Qualtrics (Qualtrics LLC, Provo, UT, USA) as a hyperlink to ~18,000 subscribers of *Greenhouse Grower Magazine* in Spring 2019. Additionally, the survey was distributed to greenhouse growers through the greenhouse extension specialists' network at land grant universities throughout the United States in Winter 2019. Recipients of this survey link were requested to participate in the survey by receiving up to three reminders (Dillman et al. 2014). In total, the survey was completed by 421 growers.

To assess representativeness of our sample to the broader population of greenhouse growers, we drew from the 2018 State of the Industry Report [hereafter, Industry Report (Greenhouse Grower 2018)]. The greenhouse operations in our sample reflect a broad range of years of operation as well as size of greenhouse operations, although our sample contains growers that are smaller and on average have fewer years in operation compared with the Industry Report. McOmber et al. (2021) provides additional detail on the comparison of our sample to the Industry Report.

The survey had four sections (see Supplemental Material). The first section collected information about the respondent's greenhouse operations and asked about growers' experience and knowledge about recycled water. The second section of the survey asked respondents questions about their knowledge and perceptions of recycled water, tap water, and treated wastewater. The third section queried the respondent's perceptions, willingness to use, and actual use of MRW, and the last section collected demographic information such as education, age, and gross greenhouse operation income. Although sections 1 and 2 established the respondent's knowledge and attitudes about recycled water, we knew from pilot testing the survey that growers have diverse understandings of recycled water and would respond to questions using their own diverse frames of reference. To establish a more uniform framing for questions specific to MRW, we introduced an informational diagram between sections 2 and 3 of the survey (see Supplemental Material or McOmber et al. 2021). This figure illustrates where MRW comes from, how it is produced, and various uses of MRW. After viewing the informational diagram about MRW, respondents were asked a series of questions about their perceptions, attitudes, and use of MRW.

For analysis, we denote our variables using "Question" followed by the main question number with any relevant subquestion number noted in parenthesis (Supplemental Material). Given our interest in understanding willingness to use MRW in greenhouse production, we focused our analysis on the 346 respondents who indicated they were involved in greenhouse production (i.e., employees with or without decision power or owners involved or not in daily decisions). The 75 respondents including 60 who did not provide an answer to the question "What is your primary role regarding your greenhouse operation?" and 15 who chose "other" and where their open-ended response indicated they were not involved in greenhouse production were excluded from the analysis. The final regression model included 268 respondents, most of whom had decision-making power either as employees (55.3%) or owners (44.7%). These 268 respondents account for missing values from Question 25 (3) and Question 25 (5), which we combined to create our targeted response variable: willingness to use MRW on food crops. Variable values were defined as 0 if respondents were not willing to use MRW to irrigate food crops whether the water directly contacted the food crop and were defined as 1 if respondents were willing to use MRW to irrigate food crops.

We considered the responses from the following questions as our independent variables: primary role in the greenhouse operation (Question 6); primary customers for greenhouse products (Question 8); primary water source (Question 9); whether any water shortage(s) was experienced over the past 5 years (Question 10); whether water is treated to improve its quality before it is used (Question 11); use of recycled water in greenhouse operation (Question 15); the approximate annual total greenhouse operation net income (Question 29); perceptions of recycled water, tap water, and treated wastewater (Question 22); and motivations and limitations on the use of MRW to grow food crops (Question 26). An additional independent variable was created from size range (Question 20) referring to the square footage floor area of greenhouse operation (1 = than 100,000 ft^2, 2 = 100,000 to 499,999 ft^2, 3 = 500,000 to 999,999 ft^2, 4 = 1 million to 5,999,999 ft^2, 5 = 6 million to 9,999,999 ft^2, missing value = no responses).

Statistical analysis. To test whether there exists a statistically significant relationship between each independent variable and the response variable (i.e., greenhouse growers' willingness to use MRW on food crops), we conducted chi-square tests of independence using a 0.05 level of significance.

A logistic regression model was used to estimate the association of one or more independent variables with the binary response variable, greenhouse growers' willingness to use MRW on food crops. The logistic regression permits evaluation of the relationship of each independent variable with the response variable while controlling for the effect from other independent variables in the model. An initial logistic regression model was built with all potential predictors and then stepwise Akaike information criterion (AIC) variable selection was used to determine the final model. The exponentiated logistic regression coefficients in the model can be interpreted as odds ratios. Odds ratio explains the odds change for willingness to use MRW on food crops when comparing a certain group of growers based on one predictor vs. a reference category. One way to quantify how well a logistic regression model classifies data is to calculate the area under the receiver operating characteristic (AUC). The value for AUC ranges from 0 to 1. The higher the AUC score, the better the model is at classifying observations into classes.

According to Hosmer et al. (2013), an AUC greater than 0.8 is considered excellent discrimination.

Results

Chi-square tests. Using chi-square tests, we found 12 independent variables significantly associated with a willingness to use MRW on food crops (Table 1). Three of these variables captured respondent concerns over water quality that made greenhouse growers less willing to use MRW on food crops. Specifically, concerns over poor quality of MRW and lack of trust in regulatory oversight over the quality of MRW limits growers' willingness to use MRW. Conversely, when growers trusted the provider that the quality of MRW is suitable for the intended use, they were more willing to use MRW on food crops compared with those who did not trust the quality (chi-square = 6.61, $P < 0.01$).

Capital or market-based incentives and growers' primary customers were also significant in affecting grower willingness to use MRW on food crops in the bivariate analysis. We found that growers who are motivated by MRW-focused monetary incentives or operational costs were more willing to use MRW on food crops. We also found that growers who thought that the cost of capital investments (i.e., to enable use of MRW) limits MRW use. Lastly, our results show that growers whose primary customers are restaurants, retail, or farmer's markets (compared with wholesale) were less willing to use MRW on food crops.

Finally, growers' knowledge about others' experiences using recycled water and growers' environmental concerns were also significant in the bivariate analysis. We observed that greenhouse growers who were motivated by the experience of other greenhouse growers using MRW *within the United States* were more willing to use MRW on food crops. However, greenhouse growers were less willing to use MRW on food crops when they thought the experience of other greenhouse growers *globally* using MRW limits use. Environmental and water security concerns also appeared to be significant in the model. Greenhouse growers who thought environmental impacts motivate use of MRW were more willing to use it on food crops, whereas growers who thought that MRW use and its effect on water security limits use were less willing to use MRW on food crops.

Logistic regression results. When controlling for multiple variables in the logistic regression model, five variables are significantly correlated with a willingness to use MRW (Table 2). First, controlling for other variables in the model, the odds that a grower is willing to use MRW on food crops increased by 225% if the quality of MRW *motivated* use compared with *limited use* or *neither limited nor motivated use*. Similarly, the odds that a grower was willing to use MRW on food crops increased by 142% if they perceived that treated wastewater was *not disgusting*, compared with those who thought it was *disgusting*. Third, if growers were motivated by others' experiences using MRW globally, the odds of being willing to use MRW on food crops increased by 173%, compared with growers who expressed others experiences globally *limited* or *neither limited nor motivated* MRW use. Fourth, the odds that a grower is willing to use MRW on food crops increased by 125% if they had no experience with water shortages, compared with those who had experienced water shortages. Finally, the odds that a grower is willing to use MRW on food crops decreased by 64.8% if they did not use recycled water (a more general term for reused water such as from onsite ponds) in their greenhouse operations, compared with those who did use it.

Discussion

Our analysis indicated that water quality and knowledge of, or experience with, MRW were central to explaining willingness to use MRW.

Water quality. Growers' positive perceptions about the quality of MRW appear to be important in the model and does increase the odds of growers' willingness to use MRW to irrigate food crops. Further, as Savchenko et al. (2018, 2019) found, public perceptions of recycled water quality also matter for consumer choices. In turn, growers seem to anticipate consumer perceptions about the quality of MRW, and it seems to impact their willingness to use it on food crops in their greenhouse operations. Growers who sell primarily to wholesale distributors, where the end user is several steps removed from the grower, were more willing to use MRW on food crops. This was in comparison to growers who had more direct contact with end users through farmers markets or restaurants and whose perceptions of MRW might have a more direct impact on their sales.

Direct and indirect experience with MRW. We asked a series of questions to understand how direct or

Table 1. Chi-square tests of independence between each survey variable with willingness to use municipal recycled wastewater (MRW) on food crops, based on 268 responses to the Greenhouse Grower survey (McOmber et al. 2021; Supplemental Material).

Variable	χ^{2i}	*df*	*P* [ii]
I trust the provider that the quality (of MRW) is suitable for the intended usage	6.6077	1	0.010**
Water quality of MRW	19.979	1	<0.001***
Trustworthiness of laboratory test results about quality of MRW	19.215	1	<0.001***
Regulatory oversight over quality of MRW	14.46	1	<0.001***
Primary customers	6.7015	2	0.035*
Capital investments to allow use of MRW	5.3784	1	0.020*
Operational costs	4.5514	1	0.033*
Monetary incentives for use of MRW	18.872	1	<0.001***
Experience of other greenhouse growers in the United States of using MRW	19.727	1	<0.001***
Experience of other greenhouse growers worldwide of using MRW	21.052	1	<0.001***
Environmental impact	13.727	1	<0.001***
Effect on water security	15.604	1	<0.001***

[i] Chi-square coefficient.
[ii] ***, **, * significant at $P \leq 0.001$, ≤ 0.01, or $P \leq 0.05$, respectively.

Table 2. Results from the logistic regression model on determining factors of willingness to use municipal recycled wastewater (MRW) on food crops, based on 268 responses of the survey (McOmber et al. 2021; Supplemental Material).

Independent variable[i]	β[i]	*SE*	Exp (β)[ii]	*P*[iii]
Water quality of MRW motivate use (compared with missing, neither or limits use)	1.1774	0.4181	3.2459	0.005**
Treated wastewater is not disgusting (compared with is disgusting)	0.8854	0.3491	2.4240	0.011*
Does not use RW in greenhouse (compared with uses)	–1.0429	0.4204	0.3524	0.013*
Others' experiences (globally) using MRW motivates use (compared with missing, neither, or limits use)	1.006	0.4146	2.7346	0.015*
No experience with water shortages (compared with did experience water shortage)	0.8112	0.4032	2.2506	0.044*
Primary customer is wholesale, other (compared with restaurants, farmers markets, retail)	0.6669	0.3448	1.9482	0.053
Does not trust that quality of RW from provider is suitable for use (compared with does trust the quality of RW)	–0.6904	0.3629	0.5014	0.057
RW is purified sewage (compared with not purified sewage)	0.7535	0.4759	2.1244	0.113
Effect on water motivates (compared with missing, neither limits nor motivates, or limits)	0.6147	0.358	1.8491	0.086
others compared with owner with daily decisions	0.5039	0.3398	1.6552	0.138
Model constant	–0.7689	0.5761	0.4635	0.182
Model AUC	0.810			
Model R^2	0.345			
Model N	268			

[i] Estimated coefficient.
[ii] Exp(β) is the exponential of the coefficients, which are the odds ratio.
[iii] *P* value for significance test on each independent variable. **, * significant at $P \leq 0.01$ or ≤ 0.05; no asterisk indicates nonsignificant at $P > 0.05$.
RW = recycled water; AUC = area under the curve.

indirect experience using MRW influences growers' willingness to use it. Growers who lacked experience using MRW were less willing to use it for irrigating food crops in their greenhouse operation. Lack of prior experience using MRW may have negatively influenced perceptions about quality and limitations in implementing the practice. Instead, experience and learning can shape positive and negative perceptions about MRW and increase growers' willingness to use it within their greenhouse operations (McOmber et al. 2021). However, it is not just direct experience that matters for growers. Indirect experience, through other growers, can also increase growers' willingness to use MRW. Results indicate that growers who knew about others' experiences using recycled water throughout the world were more motivated to use it. The influence of global experience may reflect that MRW is more widely adopted and used in agriculture internationally, particularly in countries such as Australia, Italy, and Israel (Craddock et al. 2021; Radcliffe and Page 2020), and that growers may be more familiar with use internationally than they are of other growers using MRW in the United States. Although knowledge of global experiences with MRW remained significant in the regression, knowledge of US growers' experiences with MRW did not.

Water security concerns. Demand for water and climate change threatens global agricultural water supplies (Mekonnen and Hoekstra 2016), and greenhouse growers are increasingly concerned about water security in terms of quantity and availability (White et al. 2019); yet in our bivariate analysis, we observed that these concerns limit rather than motivate recycled water use. In part, this may be because respondents were defining "water security" differently from definitions in the literature, as we did not provide a definition for the term in the survey. The effect on water security to motivate MRW use among growers was not significant in the regression. Rather, in the regression, not experiencing water shortage motivated growers' willingness to use MRW. This may suggest that greenhouse growers who do not feel water insecure are willing to experiment with alternative water supplies, whereas those who do feel water insecure are more risk averse. This explanation is consistent with our findings that direct or indirect experience and perceptions of MRW quality (perhaps garnered through that experience) motivate growers' willingness to use MRW.

Beyond education: making a case for deep engagement to improve MRW uptake. Our research suggests growers' positive perceptions of MRW quality relate to their direct and indirect experience using MRW and that these together are the most important factors motivating growers' willingness to adopt MRW in agricultural practice. Personal observation and peer acceptance can be a critical factor in influencing adoption of new innovations (Rogers 1995). Experience and knowledge about water conservation techniques can influence perceptions (Warner et al. 2018, 2020), which, in turn, can increase growers' willingness to adopt MRW within their greenhouse operations (McOmber et al. 2021). Our findings provide supporting evidence to a growing number of studies that suggest education about water conservation techniques, including alternative water sources like MRW, alone will improve their use (Dery et al. 2019; Lamm et al. 2017; Warner et al. 2018, 2020; White et al. 2019).

Education about MRW absent experience (direct or indirect) may be insufficient because negative perceptions about MRW may be multilayered and difficult to change. Positive perceptions created through trialability and observability (Rogers 1995) with MRW may help to support the intended impact of educational efforts regarding MRW and support behavioral change for adoption within the greenhouse operation. For example, although most growers did not, themselves, think that MRW was "disgusting" or "contained bacteria," they may be concerned that their customers do (Savchenko et al. 2018, 2019), which may limit their willingness to use MRW. Besides worrying about consumers'

negative perceptions, grow-ers may need to be reassured they can trust the quality of MRW. Increasing knowledge on testing, regulating, and producing MRW could increase adoption and continued use, as observed by Warner et al. (2018). Trusting regulatory authorities' ability to ensure MRW quality echoes findings from Po et al. (2003), which showed that growers' skepticism of the testing process and distrust of the responsible authorities providing MRW impeded its use but that these conditions improved when growers increased knowledge and had the opportunity to gain first-hand experience with MRW.

Efforts to improve MRW use among growers should center experience as a starting point for education of MRW. Such programs should include a process of iterative, deep engagement involving growers, extension agents, and regulatory officials that is designed to facilitate experiential and social learning. In this way, these efforts may begin to address knowledge gaps and concerns about MRW quality, while also working to build trusting relationships between all involved. Po et al. (2003) found that deep and continued engagement with growers through their participation in community-based committees provided an opportunity for growers to share their concerns and better understand quality control testing measures used to ensure the safety of recycled water. Deep engagement provided critical iterative feedback loops that allowed for greater attention to growers' diverse and evolving quality concerns and targeted informational needs in response to their specific concerns. Deep engagement among growers, water authorities, and intermediaries, such as extension agents, create critical pathways for improving adoption of new technologies. Huang et al. (2016) for example, provided insight into how deep engagement is important to changing behavior among the public when perceptions are difficult to change.

They found that participation in extension efforts improve public perceptions of water quality. By demonstrating "personal relevance" to the participant, educators can tailor information to address concerns and experiences with water quality which may be shaping diverse perceptions of recycled water. They find that this engagement is important for overcoming issues of cognitive dissonance around past experiences with water quality among the public. These lessons can also be extended to growers; by identifying points of informational intervention and support around topics of personal relevance, grower perceptions of MRW and ultimately adoption may be improved. Beyond targeting extension outreach to growers' experience with quality problems, experiential learning opportunities through simulation may also be an effective tool in facilitating learning and acceptance of recycled water practices. For example, Gottlieb et al. (2022) used an online, interactive simulation platform to help growers better understand the benefits (return on investment) of recycled water use as it pertained to each growers' greenhouse operational needs. Providing this kind of tailored information, directly relevant to the individualized needs of growers in the context of deep engagement, could be a powerful approach to helping the bridge the gap to increased recycled water use in the agricultural sector.

Conclusions

Grower education is seen as a critical pathway toward improving acceptance of MRW within greenhouse operations. However, education alone may be insufficient as entrenched concerns and perceptions about MRW quality may be difficult to shake. Thus, improving MRW uptake requires both education and opportunities for direct or indirect experiential learning and for building trust *through a process of deep engagement.*

Growers are heterogeneous with varying experiences, informational resources, knowledge and perceptions of MRW, which affect their motivations to use MRW. Our analysis finds that growers' willingness to use MRW is largely influenced by concerns over quality. Critically, these concerns coexist alongside other important factors, such as knowledge about MRW, direct and indirect experiences with MRW, and perceptions about and trust in MRW quality. As such, enhancing MRW use requires a multifaceted effort that can build knowledge of and trust in water quality through either direct experience with MRW or learning from the experiences of peers in the field. Deep engagement with growers that enables contextualized learning opportunities and tailoring information to the interests and needs of greenhouse growers should be employed to enhance acceptance of MRW.

Although our results support understanding of grower heterogeneity, further research is needed to provide a deeper understanding of those grower differences, including the ways that gender, age, race, and geography may affect growers' information needs, attitudes, and approaches regarding MRW. More research is also needed to deepen understanding of how a greenhouse growers' customer base (e.g., retail, wholesale distributors, restaurants, farmer's markets) affects growers' willingness to use MRW. Similarly, research is needed to gain a better understanding of the concerns and attitudes toward MRW of different types of customers and how to manage those concerns to improve customers' acceptance of using MRW on food crops. Such research could provide growers with insights, information, and strategies to alleviate those customer concerns paving the way for increased MRW adoption among growers.

Finally, research on the effectiveness of different types of information and modes of delivery are also critical to understanding how to tailor and deliver information about recycled water more effectively to diverse grower communities. Relatedly, future research to understand how deep engagement transforms perceptions of and trust in the quality of MRW are needed to improve MRW uptake.

Our conclusions are based on a survey of US greenhouse growers representing a broad range of greenhouse operations. Our sample is not reflective of the entire population of greenhouse growers because the largest, oldest operations were not included nor did we include international greenhouse operations. Still, the lessons we learned from this study provide insight into US grower heterogeneity and their diverse motivations and limitations for using MRW.

References cited

Bixio D, Thoeye C, De Koning J, Joksimovic D, Savic D, Wintgens T, Melin T. 2006. Wastewater reuse in Europe. Desalination. 187(1–3):89–101. https://doi.org/10.1016/j.desal.2005.04.070.

Craddock HA, Rjoub Y, Jones K, Lipchin C, Sapkota AR. 2021. Perceptions on the use of recycled water for produce irrigation and household tasks: A comparison between Israeli and Palestinian consumers.

J Environ Manage. 297:113234. https://doi.org/10.1016/j.jenvman.2021.113234.

Cultice A, Bosch D, Pease JW, Boyle KJ, Xu W. 2016. Horticultural growers' willingness to adopt recycling of irrigation water. J Agric Appl Econ. 48(1):99–118. https://doi.org/10.1017/aae.2016.2.

Dery JL, Rock CM, Goldstein RR, Onumajuru C, Brassill N, Zozaya S, Suri MR. 2019. Understanding grower perceptions and attitudes on the use of nontraditional water sources, including reclaimed or recycled water, in the semi-arid southwest United States. Environ Res. 170:500–509. https://doi.org/10.1016/j.envres.2018.12.039.

Dillman DA, Smyth JD, Christian LM. 2014. Internet, phone, mail, and mixed-mode surveys: The tailored design method. John Wiley & Sons, Hoboken, NJ, USA.

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

Greenhouse Grower. 2018. 2018 State of the industry. https://files.greenhousegrower.com/greenhousegrow/wp-content/uploads/2018/01/2018-State-of-the-Industry-Report.pdf [accessed 16 Dec 2022].

Gottlieb PD, Brumfield RG, Cabrera RI, Farnsworth D, Marxen L. 2022. An online tool for estimating return-on-investment for water recycling at nurseries. HortTechnology. 32(1):47–56. https://doi.org/10.21273/HORTTECH04925-21.

Hosmer DW, Lemeshow S, Sturdivant RX. 2013. Applied logistic regression (3rd ed). John Wiley & Sons, Hoboken, NJ, USA.

Huang P, Lamm A, Dukes MD. 2016. Informing extension program development through audience segmentation: Targeting high water users. J Agric Educ. 57(2):60–74. https://doi.org/10.5032/jae.2016.02060.

Kenny U, Regan A. 2021. Co-designing a smartphone app for and with farmers: Empathising with end-users' values and needs. J Rural Stud. 82:148–160. https://doi.org/10.1016/j.jrurstud.2020.12.009.

Lamm AJ, Warner LA, Beattie PA, Tidwell A, Fisher PR, White SA. 2019. Identifying opportunities to promote water treatment practices among nursery and greenhouse growers. HortTechnology. 29(6):687–692. https://doi.org/10.21273/HORTTECH04245-18.

Lamm AJ, Warner LA, Martin ET, White SA, Fisher P. 2017. Enhancing extension programs by discussing water conservation technology adoption with growers. J Agric Educ. 58(1):251–266. https://doi.org/10.5032/jae.2017.01251.

Maertens A, Barrett CB. 2013. Measuring social networks' effects on agricultural technology adoption. Am J Agric Econ. 95(2):353–359. https://doi.org/10.1093/ajae/aas049.

McOmber C, Zhuang Y, Raudales RE, Vadas TM, Kirchhoff CJ. 2021. What is recycled water, anyway? Investigating greenhouse grower definitions, perceptions, and willingness to use recycled water. Renew Agric Food Syst. 36(5):491–500. https://doi.org/10.1017/S1742170521000090.

Mekonnen MM, Hoekstra AY. 2016. Sustainability: Four billion people facing severe water scarcity. Sci Adv. 2(2):e1500323. https://doi.org/10.1126/sciadv.1500323.

Po M, Kaercher JD, Nancarrow BE. 2003. Literature review of factors influencing public perceptions of water reuse. CSIRO Land and WaterTech Rep. 54(03):1–33a.

Rogers EM. 1995. Diffusion of innovations (4th ed). Free Press, New York, NY, USA.

Savchenko OM, Kecinski M, Li T, Messer KD, Xu H. 2018. Fresh foods irrigated with recycled water: A framed field experiment on consumer responses. Food Policy. 80:103–112. https://doi.org/10.1016/j.foodpol.2018.09.005.

Savchenko OM, Kecinski M, Li T, Messer KD. 2019. Reclaimed water and food production: Cautionary tales from consumer research. Environ Res. 170:320–331. https://doi.org/10.1016/j.envres.2018.12.051.

Scott CA, Zilio MI, Harmon T, Zuniga-Teran A, Díaz-Caravantes R, Hoyos N, Perillo GME, Meza F, Varady RG, Neto AR, Velez MI, Martín F, Escobar J, Piccolo MC, Mussetta P, Montenegro S, Rusak JA, Pineda N. 2021. Do ecosystem insecurity and social vulnerability lead to failure of water security? Environ Dev. 38:100606. https://doi.org/10.1016/j.envdev.2020.100606.

Suri MR, Dery JL, Pérodin J, Brassill N, He X, Ammons S, Gerdes ME, Rock C, Goldstein RER. 2019. US farmers' opinions on the use of nontraditional water sources for agricultural activities. Environ Res. 172:345–357. https://doi.org/10.1016/j.envres.2019.02.035.

Warner LA, Lamm AJ, Peyton PN, White SA, Fisher PR. 2018. Identifying opportunities to promote water conservation practices among nursery and greenhouse growers. HortScience. 53(7):958–962. https://doi.org/10.21273/HORTSCI12906-18.

Warner LA, Lamm AJ, White SA, Fisher PR, Peyton PN. 2020. A new perspective on adoption: Delivering water conservation extension programming to nursery and greenhouse growers. J Agric Educ. 61(1):172–189. https://doi.org/10.5032/jae.2020.01172.

White S, Owen JS, Meajzstrik JC, Oki LR, Fischer PR, Hall CR, Lea-Cox JD, Fernandez RT. 2019. Greenhouse and nursery water management characterization and research priorities in the USA. Water. 11:2338–2357. https://doi.org/10.3390/w11112338.

Williams A, Whiteman G. 2021. A call for deep engagement for impact: Addressing the planetary emergency. Strateg Organ. 19(3):526–537. https://doi.org/10.1177/14761270211011703.

Wilson SK, von Broembsen S. 2017. Capturing and recycling irrigation runoff as a pollution prevention measure. Oklahoma State Univ, Div Agric Sci Natural Resources, Oklahoma Coop. Ext. Serv. BAE-1518. <http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-7408/BAE-1518web.pdf> [acccessed 30 Jun 2022].

Yeager T, Million J, Larsen C, Stamps C. 2010. Florida nursery best management practices: Past, present, and future. HortTechnology. 20(1):82–88. https://doi.org/10.21273/HORTTECH.20.1.82.

Radcliffe JC, Page D. 2020. Water reuse and recycling in Australia—History, current situation and future perspectives. Water Cycle. 1:19–40. https://doi.org/10.1016/j.watcyc.2020.05.005.

Supplemental Materials

Below is the survey instrument implemented for this study and administered through Qualtrics.

USDA-UConn Growers Survey

Survey Flow

Standard: Welcome Page (1 Question)
Block: Screening Question (3 Questions)
Standard: Section 1: Your Greenhouse Operation (16 Questions)
Standard: Section 2: General Water Questions (Knowledge & Perceptions) (2 Questions)
Standard: Section 3: Using Recycled Water in Greenhouse Operation (4 Questions)
Standard: Section 4: Grower Profile (6 Questions)
Standard: THANK YOU! (4 Questions)

Page Break

Start of Block: Welcome Page

Q1
Welcome to the Greenhouse Water Use Survey a collaborative effort between Department of Civil and Environmental Engineering and Department of Plant Science and Landscape Architecture at the University of Connecticut funded by the US Department of Agriculture.

This 10 minute survey focuses on water use in greenhouse operations. Results from this research will help improve understanding of water for agriculture and tailor educational materials for agricultural extension.

We appreciate your time. As a thank you for participating, you will be offered a chance to enter a drawing to win one of ten $50 Amazon gift cards when you complete the survey.

Your answers are confidential. Any identifying information will be removed before the results are shared.

By clicking the arrow below you consent to participate in the survey.

End of Block: Welcome Page

Start of Block: Screening Question

Q2
SCREENING QUESTION

Q3 For this survey, if you have owned or worked in different greenhouse projects in the past, please think about your current (or most recent) greenhouse project as you respond to the questions.

Q4 Are you involved in a greenhouse growing operation in some capacity?

- ○ Yes (1)
- ○ No, take me to the end of survey (2)

Skip To: End of Survey If Are you involved in a greenhouse growing operation in some capacity? = No, take me to the end of survey

Skip To: End of Block If Are you involved in a greenhouse growing operation in some capacity? = Yes

End of Block: Screening Question

Start of Block: Section 1: Your Greenhouse Operation

Q5 SECTION 1: YOUR GREENHOUSE OPERATION

Q6 What is your primary role regarding your greenhouse operation?

- ○ Employee (with decision power) (1)
- ○ Employee (with no decision power) (2)
- ○ Owner (involved w/ daily decisions) (3)
- ○ Owner (not involved w/ daily decisions) (4)
- ○ Other, please specify: (5) _____

Q7 What plants have you grown in your greenhouse(s) over the last 5 years? (Check all that apply)

- ☐ Leafy- and micro- greens (e.g., lettuce, spinach, persian cress, mustards, pac choi, radish, beet, orach) (1)
- ☐ Vegetables (e.g., cucumbers, tomatoes, peppers) (2)
- ☐ Herbs (e.g., basil, water cress, cilantro) (3)
- ☐ Berries (e.g., raspberries, strawberries) (4)
- ☐ Ornamentals, Perennials (5)
- ☐ Pharmaceutical / medicinal crops (6)
- ☐ Other(s), please specify: (7) _____

Q8 Who are your primary customers for your greenhouse products?

- Restaurants (1)
- Wholesale / distributor (2)
- Retail (3)
- Farmers' markets (4)
- Other, please specify: (5) _____

Q9 What is your primary source of water for your greenhouse operation?

- Purchased public or private water (1)
- Purchased treated wastewater (2)
- Surface water on my property (e.g. ponds, river, lake) (3)
- Drilled well on my property (4)
- Other, please specify: (5) _____

Q10 Have you experienced any water shortage(s) where you operate your greenhouses over the last 5 years?

- Yes (1)
- No (2)

Q11 Before you use water in your greenhouse operation, do you treat the water to improve its quality?

- Yes (1)
- No (2)

Display This Question:

If Before you use water in your greenhouse operation, do you treat the water to improve its quality? = Yes

Q12 Could you please specify how do you treat your water?

_____

Q13 What do you use water for in your greenhouse operation? (Check all that apply)

- ☐ Irrigation (1)
- ☐ Environmental control (2)
- ☐ Washing vegetables (3)
- ☐ Cleaning facilities (4)
- ☐ Other(s), please specify: (5) _____

Q14 What is the primary irrigation system used in your greenhouse operation?

- ○ Overhead sprinkler system (1)
- ○ In-pot drip system (2)
- ○ Boom system (3)
- ○ Ebb and flood benches (4)
- ○ Flooded floors (5)
- ○ Deep-water culture (6)
- ○ Hand-watering with a hose (7)
- ○ Other, please specify: (8) _____

Q15 Do you use recycled water in your greenhouse operation?

- ○ Yes (1)
- ○ No (4)

Display This Question:

If Do you use recycled water in your greenhouse operation? = Yes

Q16 Please explain what recycled water you use and how you use it in your greenhouse operation?

_____

_____

_____

_____

_____

Display This Question:

If Do you use recycled water in your greenhouse operation? = No

Q17 You indicated 'no' you do not use recycled water in your greenhouse operation. What does "recycled water" mean to you?

_____

_____

_____

_____

_____

Q18 The following questions ask about use of recycled water for irrigation of crops.

	Yes (1)	No (2)
Are you willing to use recycled water to irrigate non-edible plants? (1)	○	○
Do you have experience using recycled water to irrigate non-edible plants? (2)	○	○
Are you willing to irrigate food crops using recycled water if that water is not in direct contact with the food crop? (3)	○	○
Do you have experience using recycled water to irrigate food crops not in direct contact with the recycled water? (4)	○	○
Are you willing to use recycled water to irrigate food crops if that water is in direct contact with the food crop? (5)	○	○
Do you have experience using recycled water to irrigate food crops in direct contact with recycled water? (6)	○	○

*

Q19 How much water do you use each month on average for your greenhouse operation?

○ Approximate average water use in gallons per month: (1) _____

○ Don't know (2)

*

Q20 Approximately how much floor area do you have in your greenhouse operation?

○ Approximate floor area in square feet: (1) _____

○ Don't know (2)

End of Block: Section 1: Your Greenhouse Operation

Start of Block: Section 2: General Water Questions (Knowledge & Perceptions)

Q21 SECTION 2: GENERAL WATER QUESTIONS

Q22 Six descriptive statements appear below. For each statement, indicate "Yes" if you think it describes the type of water in each column or "No" if you think it does not.

	Recycled Water		Tap Water		Treated Wastewater	
	Yes (1)	No (2)	Yes (1)	No (2)	Yes (1)	No (2)
Contains chemicals, such as chlorine (1)	○	○	○	○	○	○
Contains bacteria or viruses (2)	○	○	○	○	○	○
Is purified sewage (3)	○	○	○	○	○	○
Is drinkable (4)	○	○	○	○	○	○
Is disgusting (5)	○	○	○	○	○	○
I trust the provider that the quality is suitable for the intended usage (6)	○	○	○	○	○	○

End of Block: Section 2: General Water Questions (Knowledge & Perceptions)

Start of Block: Section 3: Using Recycled Water in Greenhouse Operation

Q23 SECTION 3: USING MUNICIPAL RECYCLED WATER IN GREENHOUSE OPERATION

Q24 We define municipal recycled water as highly treated wastewater effluent. This treatment process (shown in Figure 1) removes or neutralizes impurities to a higher quality than most irrigation water, making the water safe for use.

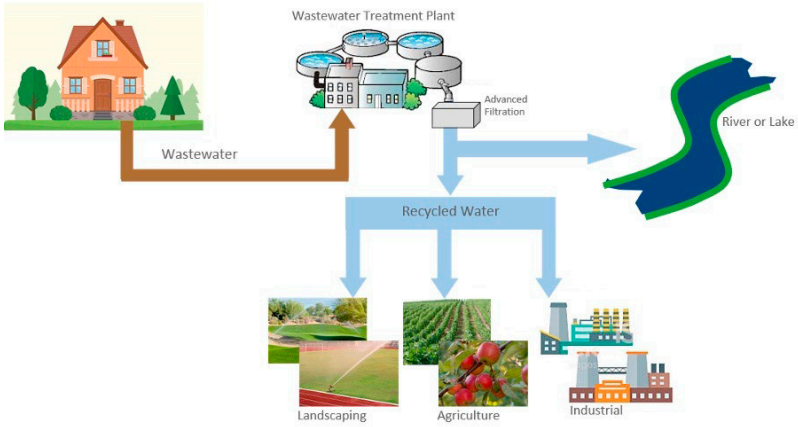

Figure 1. Process of using advanced treatment to turn wastewater into municipal recycled water.

Q25 The following questions ask about use of municipal recycled water for irrigation of crops.

	Yes (1)	No (2)
Are you willing to use municipal recycled water to irrigate non-edible plants? (1)	○	○
Do you have experience using municipal recycled water to irrigate non-edible plants? (2)	○	○
Are you willing to irrigate food crops using municipal recycled water if that water is not in direct contact with the food crop? (3)	○	○
Do you have experience using municipal recycled water to irrigate food crops not in direct contact with the recycled water? (4)	○	○
Are you willing to use municipal recycled water to irrigate food crops if that water is in direct contact with the food crop? (5)	○	○
Do you have experience using municipal recycled water to irrigate food crops in direct contact with recycled water? (6)	○	○

Q26 Below are statements about using municipal recycled water. Assuming municipal recycled water was available to you, please indicate if each statement motivates use, limits use, or neither motivates nor limits use of municipal recycled water to grow food crops.

	Limits Use (1)	Motivates Use (4)	Neither Motivates nor Limits Use (2)
a. Health effects to greenhouse staff due to contact with municipal recycled water (1)	○	○	○
b. Health effects to customers who consume crops grown with municipal recycled water (2)	○	○	○
c. Customers' perceptions regarding the use of municipal recycled water (3)	○	○	○
d. Business partners' perceptions regarding the use of municipal recycled water (4)	○	○	○
e. Crop productivity compared to irrigation with conventional water (5)	○	○	○
f. Environmental impact (6)	○	○	○
g. Effect on water security (7)	○	○	○

h. Capital investments to allow use of municipal recycled water (8)	○	○	○
i. Operational costs (9)	○	○	○
j. Monetary incentives for use of municipal recycled water (10)	○	○	○
k. Prior experience with use of municipal recycled water (11)	○	○	○
l. Experience of other greenhouse growers in the United States of using municipal recycled water (12)	○	○	○
m. Experience of other greenhouse growers worldwide of using municipal recycled water (13)	○	○	○
n. Water quality of municipal recycled water (14)	○	○	○
o. Trustworthiness of laboratory test results about quality of municipal recycled water (15)	○	○	○
p. Regulatory oversight over quality of municipal recycled water (16)	○	○	○

End of Block: Section 3: Using Recycled Water in Greenhouse Operation

Start of Block: Section 4: Grower Profile

Q27 SECTION 4: GROWER PROFILE

*

Q28 Please provide the primary zipcode for the physical location of the greenhouses, which you own and/or manage:

_____

Q29 On average, what is your approximate annual total greenhouse operation net income?

- ○ Less than $100,000 (1)
- ○ $100,000 - $499,999 (2)
- ○ $500,000 - $999,999 (3)
- ○ $1 million - $4.99 million (7)
- ○ $5 million - $14.99 million (6)
- ○ $15 million or greater (5)

Q30 Approximately how many years have you been in the greenhouse growing industry?

_____

Q31 Age:

- ○ 25 or younger (1)
- ○ 26 - 35 (2)
- ○ 36 - 45 (3)
- ○ 46 - 55 (4)
- ○ 56 - 65 (5)
- ○ 66 - 75 (6)
- ○ 76 or older (7)

Q32 Education:

- ○ Some school education, no degree (1)
- ○ High School graduate (2)
- ○ Associate degree (3)
- ○ Bachelor's degree (4)
- ○ Master's degree (5)
- ○ PhD or greater (6)
- ○ Other, please specify: (7) _____

End of Block: Section 4: Grower Profile

Start of Block: THANK YOU!

Q33 We value your participation in this survey. Thank you!

Q34 Please enter your preferred email address below, if you would like to participate in the drawing to win one of ten $50 Amazon gift cards or if you would like to receive a summary of the research results. Email addresses will be kept confidential and will not be shared or used for any other purpose.

Display This Question:

If If Please enter your preferred email address below, if you would like to participate in the drawing to win one of ten $50 Amazon gift cards or if you would like to receive a summary of the resear... Text Response Is Not Empty

Q35 You have entered your email above. Would you like to:

	My preferences:	
	Yes (1)	No (2)
Participate in the Amazon gift card drawing (1)	○	○
Receive a summary of the research results (2)	○	○

Q36 If there is any additional information you would like to add or feedback you wish to provide, please enter those notes in the textbox. Thank you.

_____

_____

_____

_____

_____

End of Block: THANK YOU!