Renewable Agriculture and Food Systems

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What is recycled water, anyway? Investigating greenhouse grower definitions, perceptions, and willingness to use recycled water

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Research Paper

Cite this article: 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. *Renewable Agriculture and Food Systems* **36**, 491–500. https://doi.org/10.1017/S1742170521000090

Received: 23 November 2020
Revised: 30 January 2021
Accepted: 8 March 2021
First published online: 6 April 2021

Key words:
Grower perception; local knowledge; reclaimed water; recycled water

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Abstract

As climate change and agriculture burden water resources globally, there is a need for more efficient water use including irrigation with recycled water in greenhouses. While research has proven that properly treated recycled water can be safe for use, many growers still express concern. Underlying most studies on growers' perceptions is the assumption that they understand recycled water the same way scholars and policy makers do—as municipally treated wastewater. We question this assumption and explore whether the ways in which growers conceptualize recycled water is associated with the ways they perceive its usability. Our findings reveal that growers define recycled water in four different ways—captured water, treated water, recirculation and in a general sense as 'reuse'. These definitions do appear to suggest trends in the way recycled water is perceived by growers. While these definitions do not significantly affect growers' willingness to use, other factors such as prior experience using recycled water appear to be significant.

Introduction

Water scarcity is one of the greatest threats to human and food security this century (Postel, 2000; Mekonnen and Hoekstra, 2016). Agricultural water demands place an immense burden on water resources, using 69% of freshwater resources globally (FAO, 2016) and 36% in the USA (Maupin *et al*., 2014). While greenhouse agricultural production tends to rely on less water-intensive irrigation methods than field grown production (Page *et al*., 2012; Ntinas *et al*., 2017; Hollingsworth *et al*., 2020), there is a growing interest in the opportunities presented by increased irrigation efficiency (Lichtenberg, *et al*., 2015) and non-traditional water sources such as recycled water (Dery *et al*., 2019). Innovations in technology and management including water conservation and the increased availability of recycled water, especially in the south and southwestern USA, offer the means for both meeting growing water demands and greenhouse industry sustainability (Garfin *et al*., 2014; McNabb, 2017). Despite the potential for innovation and the need to moderate water use, the US greenhouse industry has not been quick to adopt recycled water (Savchenko *et al*., 2019).

Researchers have sought to illuminate factors that influence agricultural producers' perceptions and use of recycled water to understand the lag in adoption (Po *et al*., 2003; Menegaki *et al*., 2009; Lamm *et al*., 2017a, 2017b; Dery *et al*., 2019); among this scholarship, there is scant research on greenhouse grower perceptions specifically. Emerging research suggests that information, experience and social capital can increase the adoption of recycled water among greenhouse growers. For example, when growers are provided with information about accessibility, safety (Lamm *et al*., 2017a) and efficacy of recycled water use (Dery *et al*., 2019), they are more likely to be willing to use recycled water. Others have linked social capital (i.e., feelings of trust, social responsibility and empathy) among growers with decisions to adopt water conservation methods in their greenhouse production (Jordan, 2005). Beyond greenhouse growers, emerging research on agricultural producers more broadly suggests that consumer perceptions—such as whether or not consumers will pay for produce irrigated with recycled water (Savchenko *et al*., 2019), can play an important role in grower decisions over what goes into their products (Dery *et al*., 2019; Savchenko *et al*., 2019). For example, Dery *et al*. (2019) found that growers' perceptions of non-traditional water sources, such as recycled water, echo consumer attitudes and contribute to their reluctance to use it on food crops. Building upon decades of research on consumers psychological aversion to the use of recycled water for drinking purposes, commonly known as the 'yuck factor' (Bruvold and Ward, 1970; Bruvold, 1972; McKay and Hurlimann, 2003; Po *et al*., 2003; Dolnicar and

Schäfer, 2009; Furlong *et al.*, 2019), Dery *et al.* (2019) found that one way to alleviate growers' concerns about recycled water is to improve public opinion about non-traditional water sources.

A fundamental assumption in these studies investigating the use and perceptions of recycled water is that producers, including greenhouse growers, define and understand recycled water in the same way that scholars do—that recycled water is 'advanced treated municipal wastewater' (Sapkota, 2019). Yet, scholars and producers may, in fact, define and understand recycled water differently. Research shows that context and social norms shape local knowledge around a given concept (Ventevogel *et al.*, 2013). In turn, norms create meaning which affects the way a concept is understood both individually and collectively (Mikhailovich, 2009). Understanding the ways in which agricultural producers and scholars define recycled water may fill critical gaps in knowledge regarding its meaning, perceptions and use among greenhouse growers.

Our study seeks to answer three research questions using greenhouse growers as a focal study group. First, how do growers define recycled water? Secondly, do the discourses growers use in their definitions of recycled water relate to the attitudes they hold about its safety? Finally, do definitions and the resulting perceptions growers hold influence their willingness to use recycled water for agricultural production? We first review the literature exploring constructs of recycled water and the role of discourse in shaping perceptions about it. Following the literature review, we share conceptualizations of recycled water as municipally treated wastewater and then problematize this definition by exploring grower definitions of the concept. Next, we present our mixed-methods approach to analyzing the nexus between growers' definitions, perceptions and willingness to use recycled water. Finally, we present our findings and conclude with the implications of our research.

Background

Defining recycled water

Today water recycling is almost universally understood by academics, engineers, wastewater practitioners and policy makers to mean 'treated wastewater' (Po *et al.*, 2003; Mikhailovich, 2009; Dolnicar *et al.*, 2011); yet, among other groups (e.g., greenhouse growers, the public), the concept is not universally understood in the same way. Although 'water reuse', 'reclaimed water' and 'recycled water' are often used interchangeably within academic circles (McClaran *et al.*, 2020), there is little scholarship that seeks to understand the discourse growers or the public use to describe recycled water or how that discourse shapes their understanding. Differences in understanding, then, are to be expected since understanding is derived from the language people use about a concept that gives it life and meaning.

Research on what the public thinks about recycled water suggests that factors such as geography, language and culture can shape the way concepts are utilized, applied and ultimately develop meaning. For example, Mikhailovich (2009) describes a 'deep and profound difference in meaning and worldview' between public stakeholders, and those differences shaped their understandings about recycled water and the language they used to describe it (Mikhailovich, 2009, 328). Discursive differences between the lay community vs policy makers and scientists created distinctions in public debates over recycled water projects and reinforced public polarization around the issue; while the former defined recycled water in negative terms as 'sewage in drinking water', the latter described recycled water in positive terms as 'water of the highest quality' (Mikhailovich, 2009, 328). Rock *et al.* (2012) found, similarly, that referring to recycled water as 'water reuse', 'recycled water' and 'water purification' evoked positive perceptions among the public whereas referring to recycled water as 'effluent', 'waste water', 'tertiary-treated wastewater' and 'toilet-to-tap' evoked negative perceptions. Dolnicar and Schäfer (2009) affirmed that 'context is crucial' to the publics' understanding of recycled water and that their understanding impacts their willingness to use it. Incompatibility between negative and positive discourses among the public can undermine efforts to bring a variety of stakeholders together to enact policies around recycled water (Mikhailovich, 2009). Thus, the language people use to define recycled water matters greatly in how they tend to perceive it.

While prior research establishes a clear link between the socially discursive constructions of water, meaning and use among the public (Dolnicar and Schäfer, 2009; Mikhailovich, 2009; Rock *et al.*, 2012), there are no studies that we are aware of that explore how growers define recycled water and the implications of those definitions on their willingness to use it. We expect that some growers will conceptualize recycled water differently than others. These differences could have repercussions in shaping growers' attitudes and perceptions about recycled water and, ultimately, their willingness to adopt recycled water in their greenhouse operations.

Methods

Methodological overview

In this section, we describe the data collection and analysis used in this mixed-methods research. First, we describe the survey development and distribution, the information sought in the survey and the representativeness of the respondents. The survey included an open-ended question—to describe what recycled water means—which provided textual data requiring qualitative methods for analysis and close-ended questions requiring quantitative analysis. Secondly, we describe the qualitative approach to coding the textual data from the open-ended survey question and describe the four broad themes we identified in this analysis. Then, we described how these themes were used to create a new variable used in the quantitative analysis. Finally, we describe the statistical methods employed in the quantitative analysis.

Survey development and distribution

A survey (included in Appendix A) was developed and pilot-tested among $n = 12$ greenhouse growers who were not included in the final sample; then, the revised survey was programmed in Qualtrics (Qualtrics, Provo, Utah, USA) for distribution. Administration of the survey included an initial invitation with an anonymous link to the complete survey and up to three reminders to encourage response (Dillman *et al.*, 2014). The survey was distributed via email to the estimated 18,000 subscribers[1] of

[1]These subscribers are owners, growers, suppliers, dealers, distributors, extension specialists and researchers engaged in the production, marketing and business management within the wholesale and retail floriculture industry who want information on flower, plant and greenhouse vegetable industry (http://lists.meritdirect.com/market;jsessionid=2300F87ECD2C96F06D85FA2257B26CF5?page=research/datacard&id=451008; https://www.meistermedia.com/greenhouse-grower/) (September 17, 2020) (Greenhouse Grower, 2018).

Greenhouse Grower Magazine in the spring of 2019 and to the network of greenhouse growers known to Greenhouse Extension Specialists at land grant universities across the USA in the winter of 2020. Ultimately, $n = 421$ completed the survey.

We used the *Greenhouse Grower* publication's *2018 State of the Industry* report (hereafter *Industry Report*) (2018) as a reference to evaluate the representativeness of our sample, in terms of greenhouse operation size and years in operation. Despite our efforts to encourage survey response, our comparative analysis suggests that, compared to the sample of greenhouse growers profiled in the *Industry Report*, our sample includes a higher proportion of responses from small-scale greenhouse operations (less than 100,000 sq. ft.) (see Table 1). While our respondents tended to have smaller operations on average, we do have some larger operations represented as 30% of respondents in our sample reported annual income of $5 million. Our survey respondents also tend to have fewer years in operation compared to the *Industry Report* (see Table 1). While we do not have a direct comparison on age, our sample reflects a broad age range.

The survey was divided into four sections. The first section asked about respondents' greenhouse operations—including whether and how recycled water was used in these operations and what the term 'recycled water' means to them. The second section of the survey provided general questions about perceptions of three different types of water: recycled water, tap water and treated wastewater. The third section inquired about the use of municipal recycled water (treated wastewater), specifically, while the last section covered demographic information (education, experience, gross income).

Table 1. Respondent demographic information for recycled water survey and industry report

	Recycled water survey	State of industry report
Size of operation (sq.ft)		
Less than 100,000	64%	53%
100,000–499,999	22%	22%
500,000–999,999	7%	10%
1 million to 5,999,999	7%	11%
6 million to 9,999,999	1%	1%
Duration of greenhouse operation (years)		
Less than 10 years	23%	11%
10–25 years	36%	24%
25–50 years	42%	38%
50–100 years	4%	22%
Annual net income (USD)		
Less than $100,000	34%	
$100,000–$499,999	18%	
$500,000–$999,999	9%	
$1 million–$4.99 million	9%	
$5 million–$14.99 million	11%	
$15 million or greater	19%	
Age of respondent (years)		
25 or younger	3%	
26–35	13%	
36–45	17%	
46–55	20%	
56–65	31%	
66–75	13%	
76 or older	3%	

Qualitative methods

Coding of growers' definitions of recycled water

In the survey, respondents were asked whether they use recycled water in their greenhouse production activities. We asked this question to understand potential knowledge and perception differences between recycled water users and non-users. If respondents answered affirmatively to this question, they were prompted to answer the following open-ended question: *Please explain what recycled water you use and how you use it in your greenhouse operation?* If they responded negatively to the original question, they were prompted to answer: *What does 'recycled water' mean to you?*

Of the 421 respondents, $n = 285$ provided qualitative responses to these two survey questions, which serve as the basis for both the qualitative and quantitative analysis for this article. Qualitative analysis was performed in NVIVO (QSR International, Burlington, Massachusetts, USA). We used thematic analysis via line-by-line open coding to categorize emergent themes from the survey responses about how respondents define and use recycled water (Gibbs, 2007; Williams and Moser, 2019). Open coding was used to identify common and recurring themes within the survey responses. We employed line-by-line coding, where each qualitative response was coded using *in vivo* codes (i.e., codes drawn directly from the text of responses, such as 'reuse') and constructed codes (i.e., thematic categorizations interpreted from the textual responses, such as 'recirculation') (Glaser and Strauss, 1999: 107; Khandkar, 2009). This coding process produced 20 recurring codes or subthemes (Table 2). These 20 codes were then grouped into four mutually exclusive thematic categories (Table 1). The four thematic categories formed the basis for the creation of a new nominal variable (Define_Recycle): 1 = *Treated Water*, 2 = *Captured Water*, 3 = *Recirculation* and 4 = *Reuse*. A fifth category, *Effluent*, was excluded from subsequent analysis because it contained only one response. This deletion left 284 respondents in our sample.

In some cases where respondents provided contradicting definitions highlighting commonly understood conceptualizations and qualifying it with their own personal definition (e.g., 'Recycled water is understood to be "X", but I think it actually should mean "Y"'), we coded those responses according to the respondent's preferred definition.

Later in the survey, participants are provided a definition of 'municipal recycled water' and visual diagrams to explain the process of water recycling. This information is as follows: *We define municipal recycled water as highly treated wastewater effluent. This treatment process (shown in Fig. 1) removes or neutralizes impurities to a higher quality than most irrigation water, making the water safe for use.* So as to not bias responses, this information was offered after respondents provided their own definition of recycled water and after they answered questions regarding their own perceptions about it.

https://doi.org/10.1017/S1742170521000090 Published online by Cambridge University Press

Table 2. Description of qualitative codes used for thematic analysis

Thematic categories	Definition of theme category	Subthemes (identified as recurring codes)	Examples of coded text in each subtheme
Captured	Responses that mention or imply a system of water catchment or reclamation—whether that is through rain harvesting or reclaimed irrigation water. Responses do not mention treatment as a necessary component to recycling water	Harvesting	We have a 10,000 gallon rainwater harvesting system to supplement the watering of orchids due to the potential harm that the chemicals city water cause the plants
		Captured	Captured rainwater, or captured excess water from irrigation
		Tanks	A collection tank to capture inside greenhouse run off
		Rain barrels	Rainwater gathered in rain barrels used for at root irrigation
		Pond	Irrigation water that is reclaimed via bioswale or pond and then used again for irrigation
Treatment	Responses that discussed a process of treatment—whether through filtering, through individual chemical treatment or through municipal systems	Treatment	Water treatment plants
		Treated wastewater	Treated wastewater
		Cleaned	We recycle irrigation water treated with plant fertilizer until the tank is emptied and cleaned
		Filtered	All irrigation water is recollected, filtered and enter the system again. New nutrients are added to the right pH and EC
		Disinfection	All drain water is treated with a UV disinfection unit
Recirculation	Responses that discuss a process in which irrigation water is not diverted, but reclaimed and reused within the same system	Ebb and flow	Flood tanks that fill the ebb and flow benches return to flood tanks
		Ebb and flood	Flood benches re-use the water. 2,2000 gallon holding tanks hold the recycled water
		Hydroponic system	Water that's been through the greenhouse once before. We do use greenhouse wastewater out in our field plots though to utilize the fertilizer run-off from the hydroponic systems
		Recirculating	Pond water, recirculated
		Aquaponics	RAS—Recirculating Aquaculture System for aquaponics
		Closed system unit	A closed system—water circulates from a tank to the plants and back. And/or water that gets repurposed for another use
Reuse	Responses that described recycled water in general, nondescript terms without a discernable or identifiable process	Reuse	Unused returned for reuse
		Second use	Second use; water already used once and then used again
		Water that has been used before	Water already used for a different purpose and not necessarily treated

Quantitative methods

χ^2 Test for association

To test whether or not two categorical variables were independent, we performed χ^2 test of independence using a 0.05 level of significance. The null hypothesis for a χ^2 test is there is no association between the two categorical variables while the alternative hypothesis is, there is an association between the two variables. The χ^2 test statistic is calculated by comparing each cell's observed count to its respective expected count, using a contingency table generated from the observed data. Pearson χ^2 tests of independence were conducted between Define_Recycle and growers' perceptions about recycled water. Specifically, respondents were asked: *For each statement, indicate 'Yes' if you think it describes the type of water in each column.* Because we were interested in their perception of recycled water, we focus on the survey question that asked respondents to indicate whether they think recycled water has *(1) chlorine*, *(2) contains viruses or bacteria*, *(3) is drinkable* and *(4) is disgusting*. We also tested the independence between Define_Recycle and growers' willingness to use recycled water.

Binary logistic regression

In addition to Pearson χ^2 tests of association between Define_Recycle and willingness to use recycled water, we

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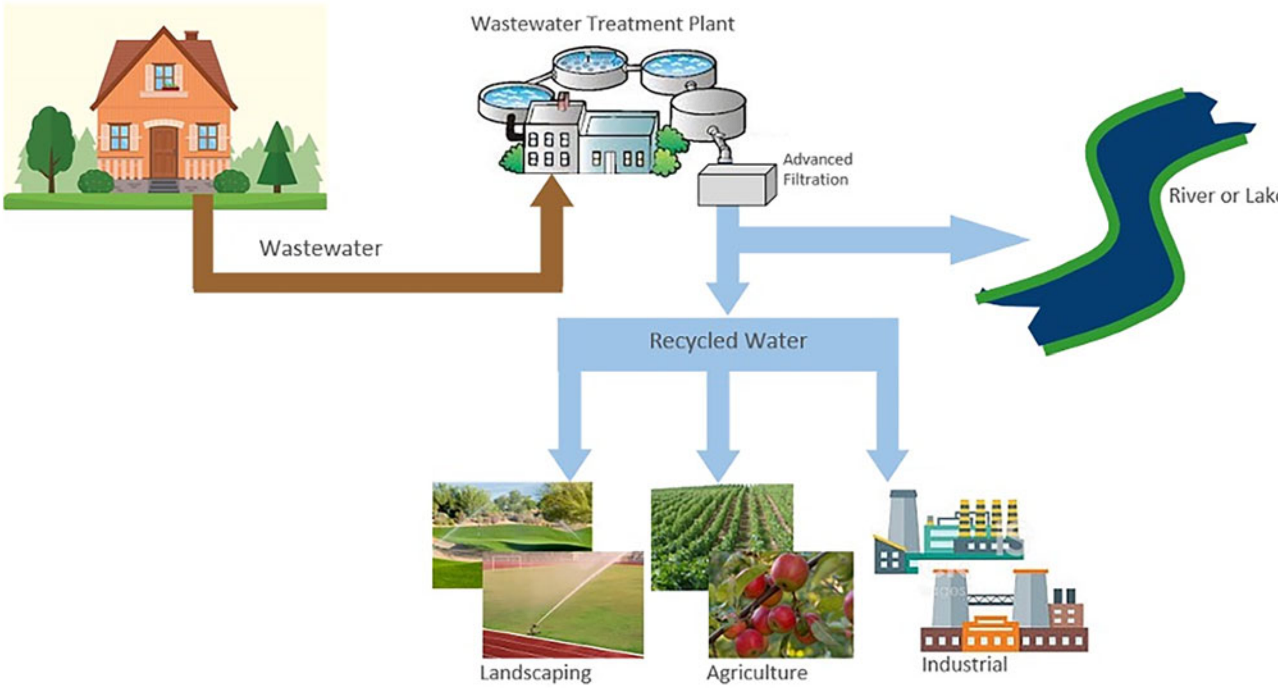

Fig. 1. Illustration showing the process whereby a wastewater treatment plant equipped with advanced filtration turns wastewater into municipal recycled water (figure presented in Section 3 of the survey).

performed binary logistic regression. We used logistic regression to test the effects of respondents' definitions of recycled water (independent variable), their perceptions of recycled water (independent variable) and their experience using recycled water (independent variable) on their willingness to use recycled water (dependent variable). Wald tests were then conducted to check the significance of individual regression coefficients in logistic regressions, with the null hypothesis being that the coefficient of a predictor is 0 and with the alternative hypothesis being that the coefficient of a predictor is not 0. Again, we used the *P* value approach, if the corresponding *P* value is <0.05, we would reject the null hypothesis and conclude that the coefficient of that predictor is not 0 and thus it is a significant predictor of growers' willingness to use recycled water.

The independent variables used in the logistic regression were previously used in the χ^2 analysis Define_Recycle, perceptions of recycled water, willingness to use recycled water and experience with recycled water. Three dependent variables (willingness to use non-edible, willingness to use edible-non-contact, willingness to use-edible-direct contact) were constructed from a set of questions posed to respondents after seeing the illustration of the recycled water treatment process (Fig. 1). Respondents were then asked about their willingness to use municipal recycled water in their greenhouse operation. Specifically, respondents were provided: *The following questions ask about the use of municipal recycled water for irrigation of crops.* Participants are then prompted to respond 'yes' or 'no' to the following questions: *(1) Are you willing to use 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) Are you willing to use recycled water to irrigate food crops if that water is in direct contact with the food crop?* Drawing from the literature on the 'yuck factor' (Po *et al.*, 2003), these questions were designed to understand whether growers expressed an increased aversion to recycled water use, once provided with a clear definition, as it is applied in closer contact to the ingestible food item.

Results and discussion

Growers' definitions of recycled water

First, we qualitatively assessed greenhouse growers' understanding of the concept of recycled water. Our thematic analysis found a clear delineation between those who viewed recycled water as a process that involves capturing of irrigation and rain run-off for reuse, and those who saw recycled water as a process that involved treatment. Of the 284 respondents, 137 described recycled water as 'captured water', often as water harvested or reclaimed, without any explicit mention of treatment as being a necessary component to recycled water (see Table 3).

For example, respondents often mentioned 'capturing' runoff or 'reclaiming irrigation water' in holding tanks or ponds. Some examples of this type of response include the following:

> 'Recycled water to me is any form of captured water, be it irrigation run off or rain then used for greenhouse use' (Respondent 14, Captured Water Category).
>
> 'Using water captured from rain runoff and/or water that has previously been used for watering crops' (Respondent 131, Captured Water Category).
>
> 'Water that has been used for some purpose within the facility and is captured for use within the facility again' (Respondent 129, Captured Water Category).
>
> 'Recycled means excess water that is recaptured to use again for irrigation' (Respondent 132, Captured Water Category).

In all, there were 73 respondents that understood recycled water to be a process that involved treatment and who were grouped in the 'treated water' category. These responses can be

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Table 3. Frequency of definition types for recycled water

Define_Recycle	Frequency
Treated water	73
Captured water	137
Hydroponics	43
Reuse	31
Total	284

subcategorized into three themes: those that identified recycled water as municipally treated wastewater, in line with the definitions presented in the scholarly literature; those that described a treatment process within the greenhouse facility; and finally, those that described treatment in very general terms. In total, ten respondents discussed recycled water as municipally treated wastewater. Some examples include:

> 'Treated water coming from municipalities wastewater' (Respondent 390, Treated Water Category).
>
> 'Treated water from a public sewage system' (Respondent 328, Treated Water Category).
>
> 'Municipal water is added to tanks which are then dosed with nutrients and acid for pH balance. This treated water runs through pipes and out emitters into channels where plants take up what's needed. The water is then collected in a trough and returns to the tank to be retreated and cycled through the system again. I am not aware of any outside recycled water from waste treatment centers that is used unless it is part of the city's municipal system already' (Respondent 178, Treated Water Category).

More often, however, were detailed discussions of reclamation and treatment processes that did not involve municipalities. Instead, this treatment was conducted at the greenhouse facility itself. A respondent explains, 'We have our own water treatment plant'. These processes are diverse, using a variety of technology to clean the water. One respondent explains, 'We return water from the benches and drain, treat it with ozone, and reuse it'. Another described how UV light was used to treat harvested water stating, 'All the leach[ate] from the gutters is collected and treated for reuse after UV system disinfection system'. Yet others describe treatment in terms of using filters, as is seen in this response where recycled water is understood as a 'water recapture system into storage tanks with a sand filter'.

Other participants merely mentioned treatment as a process in very general terms. For example, one respondent explained that recycled water is 'water treated before use'. Another described recycled water as a process where 'water applied is collected, treated and reapplied'. The lack of detail may reflect a recognition that recycled wastewater undergoes some purification process but that the particular respondent does not have a clear understanding of the processes involved.

Recirculation systems were another common way of describing recycled water, with 43 respondents providing this description. Respondents often mentioned 'recirculation', 'closed system' and 'flood floors' in their response and therefore defined recycled water in terms of recirculating irrigation systems.

In total, 31 participants provided general responses about recycled water which often lacked both a detailed description and an articulation of a process of water recycling. These responses were coded as 'reuse' and examples of this type of response include: 'Water that has been used before' and 'Recycled water means water that has been used in some capacity and is being reused for another task'.

Evaluating the experience of recycled water: users vs non-users

Next, we assess how the ways in which respondents understand and describe the concept of recycled water relates to their experience using it. Most respondents (73%) reported they did not use recycled water; of the 78 respondents who used recycled water, 28 defined it as 'captured water', 25 defined it as 'recirculation', 23 as 'treated water' and two as 'reuse'. We found a significant association between how respondents define recycled water and whether or not the respondents used recycled water ($\chi^2 = 31.18$, $P < 0.001$). Beyond this association, qualitative analysis revealed that recycled water users tend to provide more detailed explanations of recycled water than those who do not. For example, recycled water users often include both a description of the source of the recycled water (i.e., where the water is coming from) and whether and how it is treated. This was particularly evident in the captured and treated water categories, where respondents provided descriptive information about the mechanisms used for water collection (such as rain barrels or catchment systems) and, in the case of the treated water category, the methods used for water purification. The following responses are illustrative of this:

> 'All developed land in production has either French drains (outdoor areas) or runoff water from roofs that is fed to a water system consisting of three ponds, cistern, pump house and aeration. total capacity of 20 million gallons. Water is treated for ph (sulfuric acid), chlorine to sanitize and filtered before being held in a 300,000 gallon cistern'. (Respondent 34, Treated Water Category)
>
> 'All irrigation water is recollected, filtered and enter the system again. New nutrients are added to the right pH and EC'. (Respondent 89, Treated Water Category)
>
> 'Water captured off greenhouse structures and collected in pond. Water then pump from pond through activated glass 5 micron [*filter*] and treated with chlorine. Stored in 100 gallon subsurface concrete and then pressurized so use in the greenhouse facility for watering plants or cleaning greenhouse'. (Respondent 92, Treated Water Category)
>
> 'We have a 10,000 gallon rainwater harvesting system to supplement the watering of orchids with due to the potential harm that the chemicals city water cause the plants'. (Respondent 5, Captured Water Category)

While recycled water users tend to provide detailed explanations of what recycled water they use, those who do not have experience using recycled water frequently discuss the concept using more generalized and non-specific language. Of the 31 respondents who provided general definitions of recycled water and were categorized as *Reuse*, only two indicated that they had used recycled water in their greenhouse operation. Even within those categorized as *Treated Water* or *Captured Water*, respondents who provided more detail about the process involved in recycling water were more likely to have experience using it. Thus, the more detailed descriptions of recycled water by respondents appear to indicate a deeper familiarity with and knowledge of recycled water by those who use it than those who do not.

Growers' perceptions of risk

Next, we assessed how respondents' definitions of recycled water (Define_Recycle) relate to their perceptions of the safety of

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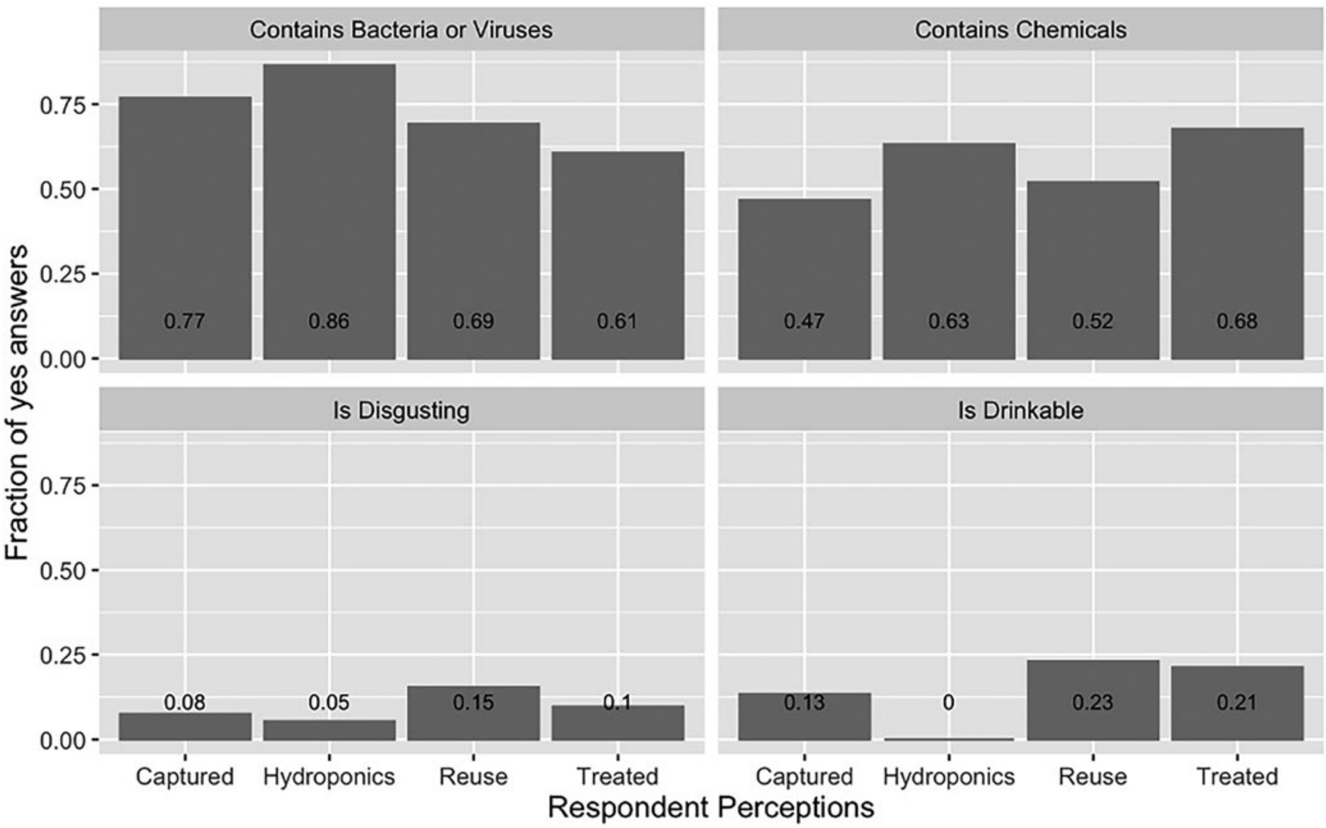

Fig. 2. Respondents perceived safety of recycled water by definition category.

recycled water. We found a significant association between how growers define recycled water and the perception that recycled water contains chemicals ($\chi^2 = 8.55$, $P < 0.05$). When chemical treatment was implied or explicitly mentioned in the definitions provided by growers (e.g., those classified as *Treated Water, Recirculation or Reuse*), they were more likely to also perceive there to be chemical contaminants in the recycled water compared to those who defined recycled water as *Captured Water* without chemical treatment (see Fig. 2 below).

We found a significant association between how growers define recycled water and the perception that recycled water contains chemicals ($\chi^2 = 9.3079$, $P < 0.05$). The majority of growers who defined recycled water as *Captured Water* (77%) and as *Recirculation* (86%) agreed that recycled water contained bacteria and virus. Given that closed system hydroponic units, in particular, are highly susceptible to bacterial and viral pathogens (Stanghellini and Rasmussen, 1994; Paulitz, 1997; Paulitz and Bélanger, 2001), this result makes sense and may indicate an awareness of this contamination risk among growers who defined recycled water as *Recirculation*. Finally, those with recycled water definitions categorized as *Reuse* (69%) thought recycled water contained bacteria or viruses. Given these respondents provided a definition that lacked specificity, these results could indicate a greater skepticism of the safety of recycled water among those who have less familiarity with or understanding of it.

We next sought to understand whether these perceived risks corresponded with attitudes toward recycled water use in a general sense (e.g., participants were asked 'is recycled water drinkable?' and, 'is it disgusting?'). While most respondents did not feel that recycled water was 'disgusting', most felt it was unsafe to drink. Those who defined recycled water as *Treated Water* responded that it was drinkable (21%). Growers who defined recycled water as captured water responded less favorably (13%). Of the 37 growers who defined recycled water as a recirculation system, none felt that recycled water was safe to drink.

Growers' willingness to use recycled water

In general, respondents were less willing to use municipal recycled water in greenhouse production as it became closer in contact with edible food products. Respondents (83%) were largely willing to use recycled water on non-edible plants. Respondents were increasingly reluctant, however, when asked about recycled water usage on food crops (see Fig. 3). When asked whether they were willing to use recycled water to irrigate food crops if the water is not in direct contact with the food crop (i.e., irrigation through the roots of the plant), 64% approved. Only 36% of respondents were willing to use recycled water if it was in direct contact with food products. Pearson's χ^2 test showed an association between recycled water users and their willingness to use municipal recycled water for non-edible plants ($\chi^2 = 8.82$, $P < 0.001$), for indirect use on edible food plants ($\chi^2 = 8.81$, $P < 0.01$) and for direct use on food plants ($\chi^2 = 13.19$, $P < 0.001$). Figure 3 shows the respondents' willingness to use recycled water with different definitions of recycled water. Those who defined recycled water as *reuse* were less willing to use municipal recycled water to irrigate non-edible plants or for non-direct contact with edible plants; however, they had the highest percentage for willingness to use on direct contact food crops when compared to other groups. Our analysis also showed that experience

https://doi.org/10.1017/S1742170521000090 Published online by Cambridge University Press

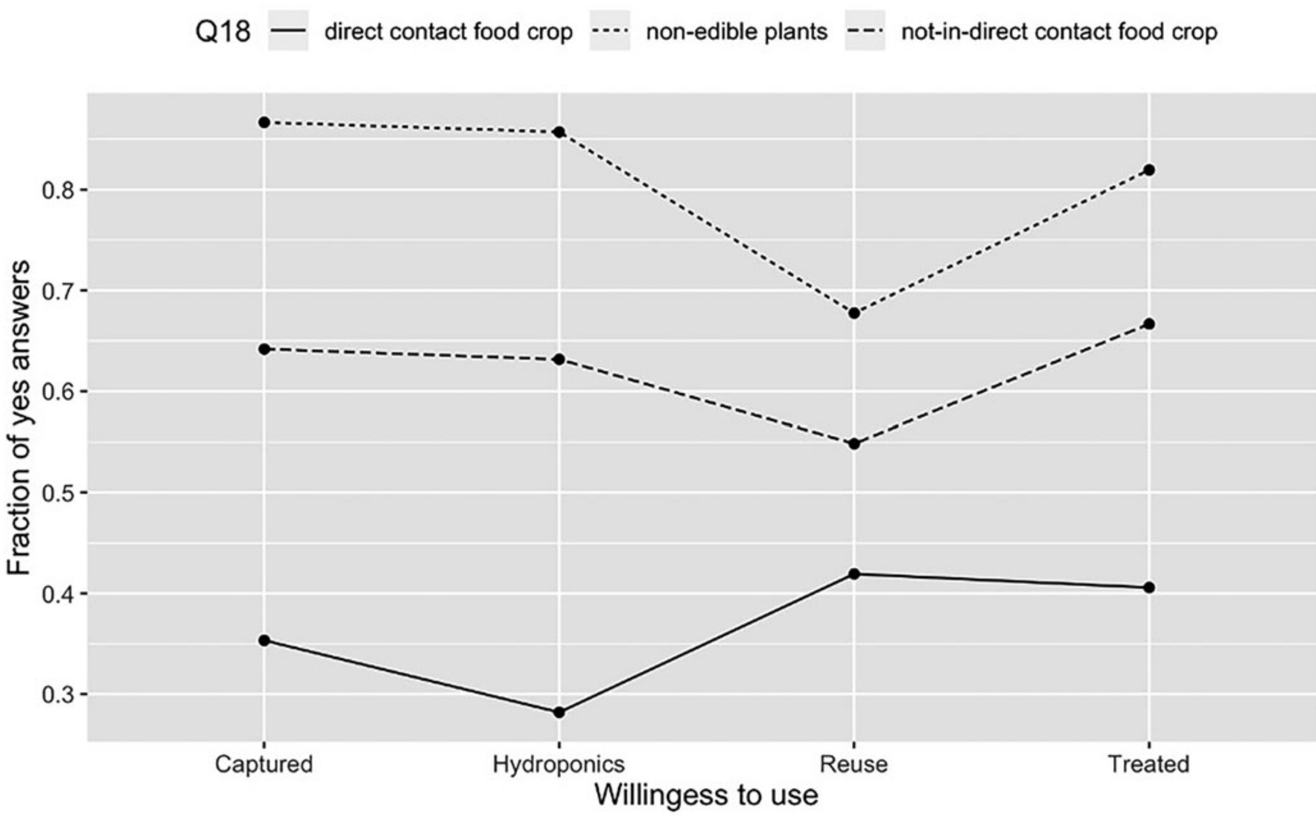

Fig. 3. Growers' willingness to use municipal recycled water based on their recycled water definitions.

with recycled water appeared to matter for growers' expressed willingness to use municipal recycled water. Among respondents, who said they used recycled water, 95% were willing to use municipal recycled water on non-edible crops. Only 55% of users were willing to use municipal recycled water directly on food crops. In comparison, only 30% of non-users were willing to use municipal recycled water on edible food crops.

We then use the three factors—recycled water definitions, experience and perceptions—as predictors for three logistic regression models with the response binary variable being growers' willingness to use recycled water on non-edible plants, not-in-direct contact and in direct-contact with food crops, respectively. The results for the final fitted models are included in Table 4 consisting of the coefficients of the explanatory variables, exponential of the coefficients, their standard errors, the Z-values and their corresponding P values for testing the significance of the predictors. All three models show that growers' experience using recycled water matters ($P < 0.05$ level) for growers' willingness to use recycled water for non-edible plants or foods in direct or indirect contact, whereas growers' definitions are not significant. The terms in the table, except the Intercept, are final selected predictors for each model using stepwise variable selection. 'Contains chemicals' and 'Contains bacteria or viruses' are dummy variables (defined as 1 = no and 0 = yes), while 'Experience with recycled water' is a dummy variable with 1 = has experience and 0 = no experience. Generally, the logistic models show that growers with experience using recycled water are more likely to use recycled water. Specifically, for the three models, the odds of being willing to use recycled water for respondents who answered that they had experience using recycled water is about 2.7–4.1 times the odds for those who had no experience. Growers who perceived recycled water contains chemicals are more willing to use recycled water than those who did not agree recycled water has chemicals, but only for irrigation of non-edible plants.

Conclusion

We expected that the discourse used to define recycled water would not be uniform and that growers may understand recycled water to mean something other than municipally treated wastewater. Indeed, only two respondents articulated a definition that acknowledged municipal treatment at all. Rather than a uniform definition of recycled water, we found that growers define recycled water differently (as *Captured Water*, *Treated Water*, *Recirculation* and *Reuse)*. This suggests that future studies should not assume agricultural producers understand recycled water in the same way as a group or that recycled water equates with municipally treated wastewater in growers' minds.

We also expected grower definitions of recycled water would shape the ways growers perceived recycled water and their willingness to use it in their greenhouse production. Indeed, we found a significant association between how growers defined recycled water and their perceptions about recycled water safety. For example, we found that growers' perception that recycled water is contaminated (by chemical or bacteria and virus) was reflective of their definition of recycled water. We did not find a significant association between growers' definition of recycled water and their willingness to use municipal recycled water, this is because most growers did not define recycled water as municipal recycled

https://doi.org/10.1017/S1742170521000090 Published online by Cambridge University Press

Table 4. Results for three logistic regression models

Term	Coefficients	exp(coef.)	Standard errors	*Z* value	*P* value
Model A: response is willingness to use recycled water on non-edible plants					
(Intercept)	1.000	2.717	0.228	4.385	0.000
Contains chemicals	0.792	2.208	0.379	2.090	0.037*
Experience with recycled water	1.413	4.107	0.552	2.561	0.010*
Model B: response is willingness to use recycled water not-in-direct contact with food crop					
Term	Coefficients	exp(coef.)	Standard errors	*Z* value	*P* value
(Intercept)	0.396	1.485	0.157	2.522	0.012
Experience with recycled water	1.010	2.745	0.347	2.910	0.004*
Model C: response is willingness to use recycled water in-direct contact with food crop					
Term	Coefficients	exp(coef.)	Standard errors	*Z* value	*P* value
(Intercept)	−1.102	0.332	0.234	−4.716	0.000
Contains chemicals	0.426	1.531	0.278	1.530	0.126
Contains bacteria or viruses	0.528	1.696	0.308	1.712	0.087
Experience with recycled water	0.996	2.709	0.302	3.301	0.001*

Note: * means that the predictor is significant at 0.05 level.

water. We did find, instead, that growers' perceptions about the safety of recycled water seemed to influence their willingness to use it. This suggests there is not a clear relationship between the language growers use to define recycled water, their perceptions about its safety and their willingness to use municipal recycled water for greenhouse production. Instead, efforts to improve growers' acceptance of using different kinds of recycled water in greenhouse production, including municipal recycled water, should start with providing information not only about what municipal recycled water is, but also its quality and safety for particular uses. This is in line with prior research (Lamm *et al*., 2017a; Dery *et al*., 2019) showing that education can be a critical pathway to increased uptake in municipal recycled water acceptance.

We also found through our qualitative analysis that growers with experience using recycled water often provided greater detail in their description of recycled water than those without experience. In contrast, general descriptions more commonly provided by non-users lack such details and give little indication of any understanding of what treatment entails. This suggests that experienced users may have a deeper understanding of what *their definition* of recycled water entails, including awareness of collection and treatment processes associated with recycled water compared to those without experience. Despite awareness of treatment processes observed in experienced users' definitions of recycled water, this awareness did not translate to an expression of understanding of municipal treatment processes.

Finally, despite negative perceptions about the safety of recycled water, 86% of growers expressed a willingness to use municipal recycled water to irrigate non-edible plants. Yet, while most growers expressed a willingness to use recycled water, the majority of respondents were not using it. The high rate of negative perceptions contrasted with the high rate of willingness to use and the low rates of actual users. This was puzzling; however, this discrepancy may be demonstrative of the differing understandings of recycled water held by greenhouse growers. Our findings suggest that, when respondents indicated mostly negative perceptions of recycled water, they were not thinking of municipal recycled water but, instead, their own definitions. In contrast, after reading the definition of municipal recycled water provided in the survey, respondents expressed more favorable attitudes in their willingness to use it. Ultimately, willingness to use municipal recycled water seemed tied to experience with recycled water however defined. When asked about their willingness to use municipal recycled water, growers with experience using recycled water are more willing to use municipal recycled water for different uses. Another explanation for this misalignment between willingness to use and actual use could be social desirability bias, which some studies have demonstrated to be important in explaining gaps between projected and practiced pro-environmental behavior (Klaiman *et al*., 2016; Moore and Rutherfurd, 2020). Further research is needed to better understand this potential effect in this study. Finally, there may be additional factors deterring use besides the ways growers define recycled water or their perception of its safety. For example, growers may not have the technical capacity to access and use recycled water, there may be negative perceptions of consumer preferences, or there may be real or perceived costs of implementation that deter use. This suggests that while language and understanding of recycled water is important, there may be other factors to surmount to improve uptake of recycled water in greenhouse operations that cannot be addressed through education alone.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S1742170521000090.

Data. The data that support the findings of this study are available from the corresponding author, C.K., upon request.

Financial support. This work is supported by Agriculture and Food Research Initiative Water for Agriculture grant no. 2017-69007-26311/project accession no. 1011821 from the USDA National Institute of Food and Agriculture.

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