Executive Summary

Assessing the State of Knowledge and Impacts of Recycled Water Irrigation on Agricultural Crops and Soils (4964)

ES.1 Key Findings

- New cultivars are needed, and development will be supported by further research into salt tolerant under field conditions and to better characterize plant response to salinity in heterogeneous soil conditions, particularly under microirrigation as salinity in the soil water (ECsw) is continuously changing over space and time.
- Management practices such as blending, cycling, and sequential use should be adopted when saline-sodic recycled water is used for irrigation.
- The quality of the recycled water can contribute to the number of heavy metals in agricultural soils affecting the microbiological balance of soils and reducing soil fertility.
- When agricultural fields are irrigated with recycled water, constituents of emerging concern (CECs) are unlikely to significantly accumulate in the soil, as most CECs are susceptible to degradation in multiple pathways. However, due to the incapacity to evaluate the cocktail effect of CECs, as well as lack of knowledge regarding the toxicity of CEC transformation products, the actual risk may be underestimated.
- To date, there is little evidence to suggest that adequately treated recycled water poses more risk in terms of waterborne microbial pathogens for produce-related illness or outbreaks than other sources of irrigation water, but epidemiological and quantitative risk assessment models suggest that guidelines for the use of recycled water should be regionally specific and consider overall population health.

ES.2 Background and Objectives

Population growth, rapid urbanization, and climate change have been contributing to water scarcity in many regions in the world. Access to adequate and safe freshwater is one of the grand challenges of this time (Sheidaei et al., 2016). Accounting for 70% of global freshwater withdrawals, agriculture is suffering the greatest impact from the water shortage (Norton-Brandão et al., 2013; FAO, 2017). To relieve the pressure on water supplies, municipal-treated wastewater (referred to as recycled water here forth) has been recognized as an important alternative source for irrigation water and is increasingly being applied in arid and semi-arid regions (Hamilton et al., 2007; Qadir et al., 2010; Grattan et al., 2015; Otoo and Drechsel, 2018). In California, about 46% of treated wastewater is recycled for agricultural use, while in Florida, the fraction accounts for 44% (Bryck et al., 2008). In China, recycled water irrigation began in 1957 and the reclamation rate of treated wastewater increased to 62% in 2014 in the cities that pioneered the implementation of wastewater reclamation and reuse (Wang et al., 2017; Zhang et al., 2018). Wastewater reuse has been long practiced in the Mediterranean basin, especially in the more water-scarce regions where the treated wastewater reuse is up to 5-12% of the total amount of treated wastewater effluent (Rygaard et al., 2011; Agrafioti et al., 2012; Kathijotes and Panayiotou, 2013; Kellis et al., 2013; Navarro et al., 2018; Saliba et al., 2018). Overall, GIS-based analysis has shown that the land area irrigated with recycled water increased from 20 million hectares in 2007 to 36 million hectares in 2017, which represents approximately 10% of the world irrigation area (Hamilton et al., 2007; Thebo et al., 2017). The reuse of treated wastewater offers many potential benefits, such as 1) decreasing stress on freshwater supply; 2) reducing cost and energy consumption (Meneses et al., 2010); 3) recycling nutrients and helping maintain soil fertility (Hanjra et al., 2012; Becerra-Castro et al., 2015; Hassena et al., 2018;); 4) reducing discharge from sewage treatment plants into the environment (Meneses et al., 2010; Plumlee et al., 2012); and 5) avoiding the impact of new water supply developments (e.g., dams, reservoirs).

Impacts of recycled water used for irrigation of agricultural lands are generally voiced and listed in the following categories:

- Reduction of the yield of crops due to the higher salt levels
- Injury to crops and ornamentals from specific elements (e.g., sodium, and boron)
- Degradation of soil structure in the long term due to higher sodium levels—or lower calcium and magnesium concentrations
- Degradation of groundwater quality as a result of leachates from the root zone, ultimately arriving at the water table and mixing with ambient water in an unconfined aquifer underlying the recycled-water-irrigated lands
- Uptake of CECs into the edible tissues of plants and detected levels of those compounds in humans consuming crops grown with recycled water
- Higher costs imposed on utilities due to the higher treatment levels that may be required to mitigate some of the above impacts
- Increased yield of some crops due to higher levels of nutrients in recycled water, thereby reducing fertilizer requirement

The overall research objective of this project is to assess the state of knowledge and impacts of recycled water irrigation on agricultural crops.

ES.3 Project Approach

The research team used a three-pronged approach to assess the state of knowledge and impacts of recycled water irrigation on agricultural crops.

- First, research conducted to date was reviewed and summarized, highlighting conditions under which significant impacts have been reported. Classical texts and contemporary literature on recycled water reuse for irrigation were reviewed.
- Second, the team worked closely with the project partners (utilities that supply recycled water for irrigation [Monterey One and Pajaro Valley Water Management Agency]) and access their water quality characteristics, farming patterns, and farmers' responses to the use of recycled water.
- Third, the research team collaborated with researchers from other countries that use recycled water for agricultural irrigation to collate data and information from their experiences with using recycled water for irrigation. This was done in form of select case studies in Australia, Israel, Spain, and Chile.
- A draft final report was prepared for review by the internal QA/QC team before submission to The Water Research Foundation.

ES.4 Results

More research is needed to develop cultivars that are more tolerant in field conditions and to better characterize plant response to salinity in heterogeneous soil conditions, particularly as drip and other low-pressure irrigation systems become more and more prevalent. This new information is critical as recycled water produced by various technologies continues to expand in arid and semi-arid climates.

The use of recycled water high in sodium and potassium can adversely affect soil in the form of reduced infiltration, poor soil tilth, and poor aeration resulting in anoxic conditions in the root zone. These negative impacts can be minimized with amendments like gypsum, sulfur, and sulfuric acid. Management practices such as blending, cycling, and sequential use should be adopted when saline-sodic recycled water is used.

The quality of the recycled water can contribute to the number of heavy metals in agricultural soils affecting the microbiological balance of soils and reducing soil fertility. Such impact can negatively soil health.

When agricultural fields are irrigated with recycled water, CECs are unlikely to significantly accumulate in the soil, as most CECs are susceptible to degradation in multiple pathways. Studies to date have suggested that CECs introduced into the soil via irrigation are mainly accumulated in the surface soil layer; only CECs with low sorption capacity and long persistence may be leached appreciably under intensive or long-term irrigation. However, due to the incapacity to evaluate the cocktail effect of CECs as well as lack of knowledge regarding the toxicity of CEC transformation products, the actual risk may be underestimated. More research is urgently needed to fill these knowledge gaps to better elucidate the fate and risks of trace-level CECs in the recycled water irrigation-soil-plant-human continuum and ultimately the exposure to humans via dietary intakes of the impacted agricultural products, as well as the ecological risk of CECs toward non-target terrestrial organisms.

To date, there is little evidence to suggest that adequately treated recycled water poses more risk in terms of waterborne microbial pathogens for produce-related illness or outbreaks than other sources of irrigation water, but epidemiological and quantitative risk assessment models suggest that guidelines for the use of recycled water should be regionally specific and consider overall population health.

Strict regulations and successful case studies have helped to build public acceptance of recycled water reuse for irrigation in California, Arizona, Texas, and Florida. Other countries such as Australia, Chile, Israel, and Spain have also developed successful recycled water reuse projects.

ES.5 Benefits

The project findings fill critical knowledge gaps on the impact of recycled water reuse on soil and crop productivity. Specifically, utilities, farmers, and policymakers will find information on the potential impact of recycled water salinity and sodicity important. Utilizers and policymakers will also find information on CECs and heavy metals relevant to their operation. For example, the finding that because agricultural fields are irrigated with recycled water, CECs are unlikely to significantly accumulate in the soil, as most CECs are susceptible to degradation in multiple pathways, will be useful to the utilities that supply recycled water to growers. Current research also indicates the risk from waterborne microbial pathogens for produce-crop is not different from that of crops irrigated with freshwater.

Related WRF Research

Project Title	Research Focus
Addressing Impediments and Incentives for Agricultural Reuse (4956)	Agricultural water reuse has the potential to increase resilience of water and agricultural systems through benefits such as irrigation enhancement, nutrient management, water supply diversification, and compliance with water quality permits. However, wide-ranging yet surmountable barriers and tradeoffs hinder realization of these benefits and scaling reuse. This project features a guidebook highlighting specific strategies for addressing barriers to agricultural water reuse, and it includes case studies. While the specific drivers

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	and challenges could vary widely across contexts, the most successful agricultural water reuse projects invariably address multiple objectives and deliver co-benefits to diverse stakeholders. They do this through early, ongoing, and strategic stakeholder engagement and partnerships. This guidebook supports water managers, regulators, and the agricultural sector in identifying and overcoming barriers to agricultural water reuse across diverse geographic and agricultural contexts. Published in 2023. Research partners: Foundation for Food and Agriculture Research and Metropolitan Water District of Southern California.
Evaluating Economic and Environmental Benefits of Water Reuse for Agriculture (4829)	Water reuse in agriculture provides many important economic, environmental, and social benefits. Traditional cost-effectiveness approaches that focus only on financial metrics provide an incomplete picture of the true economic and societal value of these reuse projects. There is a need for greater understanding of the economic, environmental, and social tradeoffs of using recycled water and other nontraditional supplies for agricultural irrigation. This project addressed these challenges by conducting an evidence-based review of common benefits and costs of agricultural water reuse projects, developing guidance and tools to aid in benefit identification and accounting, and demonstrating the application of these tools to case examples. In addition, an online benefit library was developed outlining the benefits and costs associated with agricultural water reuse; the benefit library is available at https://bit.ly/37SR0VT. Research partner: Pentair Foundation. Published in 2021.
Agricultural Reuse-Impediments and Incentives (4775)	This study is a global inventory of successes, delays, and setback in the process of switching from various traditional sources to recycled water for agricultural irrigation. The project used multiple methods to evaluate the impediments and incentives impacting the use of recycled water in agriculture, and how their relevance differed among different stakeholder groups. Analyses were conducted at the project, regional, national, and global scales, and included the perspectives of various stakeholder groups, including water and wastewater utilities, growers, and regulators. The research included a comprehensive review of the literature, interviews with utilities and farmers, review of water utilities' planning documents, a spatial assessment of irrigated farmlands and wastewater treatment plants, and case studies of projects in California, Florida, Idaho, Colorado, Australia, Israel, and Japan.

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