Executive Summary

Developing a New Foundational Understanding of SAR-Soil Structure Interactions for Improved Management of Agricultural Recycled Water Use (4963)

ES.1 Key Findings

- Sodium Adsorption Ratio (SAR) and Cation Ratio of Soil Structural Stability (CROSS) were assessed in long-term field experiments, greenhouse studies, and soil columns to determine their effectiveness in predicting the negative impacts of using recycled water for irrigation on soil sodicity.
- Overall, CROSS proved to be a more reliable tool for predicting the impact of recycled water reuse on soil sodicity and permeability.
- Continuous irrigation with recycled water having a high CROSS value led to reduced strawberry productivity, and the salt uptake aligned with the cation composition of the water.
- To reclaim sodic soils effectively, it is recommended to employ a combination of management strategies, such as using chemical amendments (e.g., gypsum) along with soil profile modification or implementing phytoremediation techniques. These approaches enhance the effectiveness of sodic soil reclamation.

ES.2 Background and Objectives

Numerous studies have reported reductions in soil permeability resulting from the use of marginal recycled water for irrigation due to increased Exchangeable Sodium Percentage (ESP). The increase in soil ESP causes the breakdown of soil aggregates, followed by the swelling and dispersion of clay particles which leads to soil crusting, loss of porosity, and reduced permeability. If the sodium adsorption ratio (SAR) and the EC of the irrigation water are known, the effect of using recycled water on soil permeability (as a proxy for structure) can be predicted using empirical relationships. There is a vast body of literature on the negative impacts of sodium on soil structure. However, emerging research has shown that potassium and magnesium can also impact soil structure negatively and need to be included in irrigation water quality assessment criteria. A new criterion known as the Cation Ratio of Structural Stability (CROSS) is being advocated as a better predictor of potential soil permeability problems arising from the use of recycled water for irrigation. This is because CROSS accounts for the dispersive effects of exchangeable potassium and magnesium. The study objectives were to:

1. Conduct a literature review to document the state of knowledge.
2. Evaluate recycled water quality requirements to minimize long-term impacts on soil structure.
3. Conduct experiments investigating crop/soil/recycled water interactions in greenhouse and laboratory environments.
4. Evaluate the long-term impact of recycled water use for irrigation on commercial fields.
5. Investigate remediation options for sodium-affected soils.
6. Summarize project findings in a final WRF report.

ES.3 Project Approach

Task 1: The team conducted an exhaustive review of the applicable literature, tracing the state of knowledge on irrigation water quality and its impact on soils and crops. Special attention was reserved for past and most recent scientific research and refinements in the basic understanding of the SAR/CROSS/EC impact on soil permeability.

Task 2: On the basis of the findings from Task 1, SAR values from past studies were recalculated to account for recent findings about other influences on soil structure and its stability. Based on the new calculations, generalized recommendations were made to compensate for the negative impacts and ameliorate the effects of irrigation with recycled water.

Task 3: Conducted experiments investigating crop/soil/recycled water interactions impact on crop yield and soil structure in greenhouse and soil columns.

Task 4: Evaluated sustainability of long-term use of recycled water irrigation using multi-year soil sampling data from field sites in Monterey One Water and Pajaro Valley Water Management Agency. The team compared control sites (i.e., sites that have received recycled water irrigation) to sites that have continuously received recycled water for over 20 years.

Task 5: Investigated pros and cons of various remediation options for sodium-affected soils. Recommended sodic soil management strategies were based on a thorough investigation of practices from different regions of the work.

Task 6: The compilation of a final report was based on summarizing the project findings.

ES.4 Results

In conclusion, the findings of this study confirm that $CROSS_f$ (derived from the relative flocculating power of K and Mg) is a more robust tool for predicting the negative impacts of different recycled water qualities on soil structure compared to SAR. Practitioners should consider using $CROSS_f$ instead of SAR when assessing sodicity impacts. Moreover, changes in $CROSS_f$ proved to be a more reliable indicator of observed differences in recycled water quality delivered to farmers in the Monterey One Water service area along the Central Coast of California. When it comes to agriculture, shallow soil sampling is more likely to detect salinity and sodicity risks when $CROSS_f$ is utilized rather than SAR. Even at sites with recycled water at equilibrium or decreasing salinity, harmful salinity levels were observed in the 24-36" soil profile in poorly drained soils. When Na levels exceed 10 meq/L, the changes in CROSSf levels were more significant than the changes in SAR. Additionally, $CROSS_f$ exhibited a stronger correlation with Catio Exchange Capacity (CEC) compared to SAR.

In greenhouse and soil column experiments, $CROSS_f$ outperformed SAR as a predictor of reduced infiltration rates. For instance, the correlation between infiltration rate and $CROSS_f$ was (R^2=0.6), while it was (R^2=0.2) with SAR. The average plant biomass showed the highest correlation with cation ratios for different recycled water qualities, particularly with $CROSS_f$. The most commonly used method for reclaiming sodic soils and saline-sodic soils has been the application of chemical amendments, such as gypsum, to replace Na^+ with Ca^{2+} in the exchange complex. Phytoremediation has also proven to be an effective and cost-efficient method for reclaiming sodic soils, as demonstrated in various research studies. In some cases, soil profile modification through deep soiling has successfully reclaimed sodic soils. It is recommended that producers employ a combination of reclamation strategies based on local conditions, considering factors like the cost and availability of gypsum, soil type, and the availability of water for leaching.

The use of recycled water for irrigation has been practiced along the Central Coast of California for 14 (from 2009 PVW) to 25 years (from 1998 M1W). Long-term soil salinity and sodicity studies were initiated to track changes in soil salinity and alkalinity and the negative impacts associated with using recycled water. The team found that the wide-scale adoption of drip irrigation in the study area has resulted in significant decreases in the volume of delivered water and no widespread increases in soil salinity, but more work is needed to evaluate sodicity impacts.

ES.5 Benefits

Growers often need to test the quality of the water they receive on their farms. This testing may be required by state agencies or by buyers of their agricultural products. Utilities, responsible for delivering water including recycled water, have a vested interest in obtaining accurate water quality data for their users. In some cases, this data is necessary for reporting purposes. Depending on the complexity of acquiring and delivering alternative water sources (e.g., recycled water, groundwater, surface water), various methods can be employed to evaluate water quality. However, it is evident that simple averages are not reliable. Therefore, it is crucial to adopt a comprehensive and accurate water quality sampling protocol based on weighted averages. By using the $CROSS_f$ criteria, which better reflects differences in delivered recycled water quality to farmers, utilities can make more informed decisions about recycled water quality assessments.

Notably, harmful salinity levels were observed in the soil profile depth of 24-36 inches, while the delivered water was assessed as having either equilibrium or decreasing salinity trends. This information holds significant importance for agricultural producers. It can be utilized to develop mitigation strategies, such as applying soil amendments e.g., gypsum, modifying tillage techniques, and enhancing drainage, to address the issue. The data clearly demonstrated that deep plowing, which exposes the 24–36-inch soil profile, effectively increased salinity levels in the 1-12 inch soil profile to unacceptable levels. Consequently, it is necessary to develop soil sampling methods that account for temporal and spatial variations in salinity and sodicity, tailored to the specific characteristics of the agricultural production system.

Practitioners should consider using $CROSS_f$ rather than SAR when assessing the impact of soil sodicity. A $CROSS_f$ value of 10 has been identified as the critical threshold, indicating high exchange sodium levels and low calcium and magnesium levels, which can lead to soil permeability issues and potential reductions in crop yields and quality. Utilities are encouraged to utilize this threshold as a guide for interpreting $CROSS_f$ values.

Related WRF Research

Project Title	Research Focus
Assessing the State of Knowledge and Impacts of Recycled Water Irrigation on Agricultural Crops (4964)	This project will assess the state of knowledge and impacts of recycled water irrigation on agricultural crops by (1) investigating how and to what degree salinity, sodium, and chloride affect growth and production of different crops (including grain crops, vegetables, fruits, and other specialty crops); and (2) evaluating growth and productivity of crops currently irrigated with recycled water, and the association with soil health and recycled water properties. The research will provide management guidelines for sustainable water reuse with different crops and cropping systems, along with communication and outreach pieces, such as fact sheets, guidebooks, or white papers, that can be utilized by growers. Research partner: California State Water Resources Control Board.
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

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	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 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. 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. Published in 2019.

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