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Irrigating citrus with reclaimed municipal wastewater

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Project Summary

Drought and water shortages are becoming an unavoidable crisis in arid regions. As a result, cities are considering switching agricultural irrigation over to reclaimed water to free up good quality ground water for municipal uses. However, reclaimed water can decrease hydraulic conductivity in the soil because it contains a high concentration of dissolved salts and sodium. Sodium reduces hydraulic conductivity by swelling and dispersing clay particles in the soil thus reducing the water-conducting pores. Reduced water infiltration may cause ponding, root rot and damage to crops. Furthermore, high concentration of boron found in recycled water can lead to toxicity in plants like citrus.

The purpose of these laboratory experiments was to determine the effect of reclaimed water on hydraulic conductivity and changes to the boron concentration in soils cropped to citrus. Results show that reclaimed water can significantly decrease hydraulic conductivity on soils found in Riverside orange orchards. Soils with horizons of clay accumulation showed a greater reduction in hydraulic conductivity and higher boron adsorption. This suggests that farmers might have to change their irrigation practices if they are forced to use reclaimed water for irrigation.

Problem

California just experienced the longest drought in recent history and its effects have taken a toll on the availability of drinking water for Southern California. As a result, reclaimed water is seen as a good alternative to higher quality well water. However, citrus and avocado growers are concerned that elevated concentrations of boron, salts, and surfactants in reclaimed water could adversely affect their orchards. Reclaimed water can decrease saturated hydraulic conductivity in the soil due to it's higher concentration of dissolved salts and sodium. Sodium reduces hydraulic conductivity by swelling and dispersing clay particles in the soil thus reducing the water-conducting pores. Reduced water infiltration may cause ponding, root rot, and damage to crops.

The scientific literature contains conflicting reports on the "permissible limits of boron" recommended for "sensitive crops" such as citrus and avocadoes. The current safety guidelines, published by the California State Water Resources Control Board in 1984, state that a boron concentration of 0.7 mg/L in irrigation water is safe for all crops in California (Pettygrove and Asano, 1984). This guideline is more than double the "permissible limits of boron" reported by the U.S. Salinity Laboratory which recommended that "sensitive crops," which include citrus and avocado, should not be irrigated with water containing more than 0.33 mg/L boron (USSL Staff, 1954, page 81). Upon further investigation, it appears that the 1984 California guidelines mistakenly adopted limits for boron in **irrigation water** that were originally reported for the boron limits in **soil water** (Eaton, 1944; Pettygrove and Asano, 1984; Maas, 1984).

The purpose of these laboratory experiments was to determine the affect of reclaimed water on saturated hydraulic conductivity and re-evaluate the guidelines for irrigation with respect to boron concentrations in soils cropped to citrus (Riverside, CA).

Research Objectives

The objective of these experiments is to determine the affect of reclaimed water on saturated hydraulic conductivity and re-evaluate the guidelines for irrigation with respect to boron concentrations in soils cropped to citrus (Riverside, CA).

Particular attention was given to horizons of clay accumulation since they are expected to show a greater reduction in hydraulic conductivity and boron adsorption. The surface horizon and a deeper horizon were selected for evaluation. Blending water, mixing lower salinity water with reclaimed water is a common practice to improve water quality. Therefore, a blend of reclaimed water and the control was included as a treatment in this experiment.

Methodology

Evaluating the toxicity of reclaimed water to citrus is difficult in a short-term study because of the adsorption capacity of soils. Irrigation of a mature orchard with reclaimed water would require several years before the adsorption capacity of the soil is satisfied and equilibrium conditions are approached. A way to overcome the adsorption problem is to grow trees in sand tanks using nutrient solutions. However, there is concern that high calcium concentrations in the nutrient solutions will reduce the toxicity of the B because of calcium-borate complexes (Steve Grattan, U.C. Davis, personal communication).

Also, a high concentration of calcium affects membrane integrity and this is a factor affecting specific ion toxicity (Grattan and Grieve, 1999). Thus, we proposed a two prong approach to evaluating B-toxicity to citrus and the effects of Na and surfactants on soil permeability.

We are currently using laboratory experiments to determine B-adsorption constants and the effects of the reclaimed water on hydraulic conductivity parameters of the citrus soils in Riverside County. Hydraulic conductivity studies were done with repacked soil columns in the lab and with portable parameters in the field.

These measurements will be used as input to the soil/water/plant models SWS and UNSATCHEM, available from the USDA Salinity Laboratory (Suarez and Simunek, 1997; Suarez and Vaughan, 2001; Suarez, 2005)). This model includes variations in soil properties with depth, and changes in soil permeability due to changes in SAR over the growing season. Boron adsorption is modeled using the constant capacitance model (Goldberg et al., 2000).

The sample location was a mature orange grove located in the Riverside Greenbelt area, GPS coordinates 33^{o} 53’ 30” N, 117^{o} 25’ 59” W. The soil found in this orchard was representative of other soils located in the Greenbelt area and is classified as an Arlington loam. Moisture temperature regime is xeric with dry hot summers and cool winters.

Site locations were selected with a random sample model. EPA hand auger soil sampling procedures were implemented using a continuous sample method. The sample site was located in the irrigation furrow approximately 2 meters away from the base of the tree. Soil was collected with a 3 inch metal hand auger. Soil sampling through the full soil profile is essential because of the subsoil chemical and physical properties are expected to be the biggest problem. After collection, the soil was air dried at 120 °F. Then, the soil was hand sieved through a 2 mm sieve to remove gravel from the fine earth fraction. The surface horizon and a deeper horizon were selected for analysis; 0-20 cm and 40-60 cm. Soil texture was determined in the lab with Particle Size Analysis. Bulk density and organic matter content were determined in the lab. See soil data chart.

Soil Data Chart					
Depth (cm)	% Clay	% Silt	% Sand	Column g/cm^3	% Organic Matter
0-20	23	33	44	1.54	2.0
40-60	27	42	31	1.61	1.5

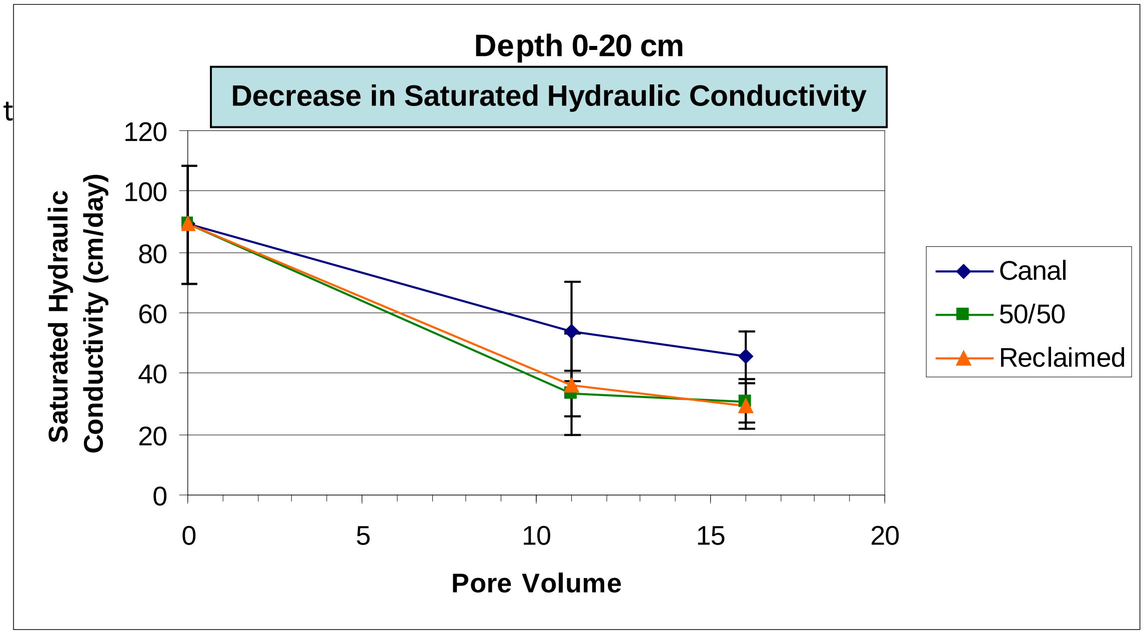
The soil was packed in 15 cm PVC columns with a 5 cm inside diameter. One end of the column was covered with cotton gauze and the edges of the gauze were taped to reduce evaporative loss. Each column was filled with 200 g of soil in 50 g increments. Soil was packed to approximately the same density by using a drop-compactor. Initial hydraulic conductivity rates were measured using Gage Canal water. Because Gage Canal water has been used to water these orchards for over 130 years, Gage Canal water was used as a control.
Saturated hydraulic conductivity (Ksat) was determined using Darcy's Law with a constant-head model. Columns were allowed to reach a steady state before rates were measured. Plant available boron concentration was determined by hot water extraction. Three water treatments were selected. See chart attached. Water was applied in 100-200 mL increments. To simulate field conditions, columns were allowed to dry between applications of water.

Water Quality	**Gage Canal (Control)**	**50/50 (reclaimed/control)**	**Reclaimed**
EC (mS/cm)	**0.58**	**0.77**	**0.90**
pH	**7.9**	**7.9**	**7.6**
Alk (mg/L $CaCO_3$)	**165**	**177**	**177**
SAR	**0.60**	**1.3**	**1.8**

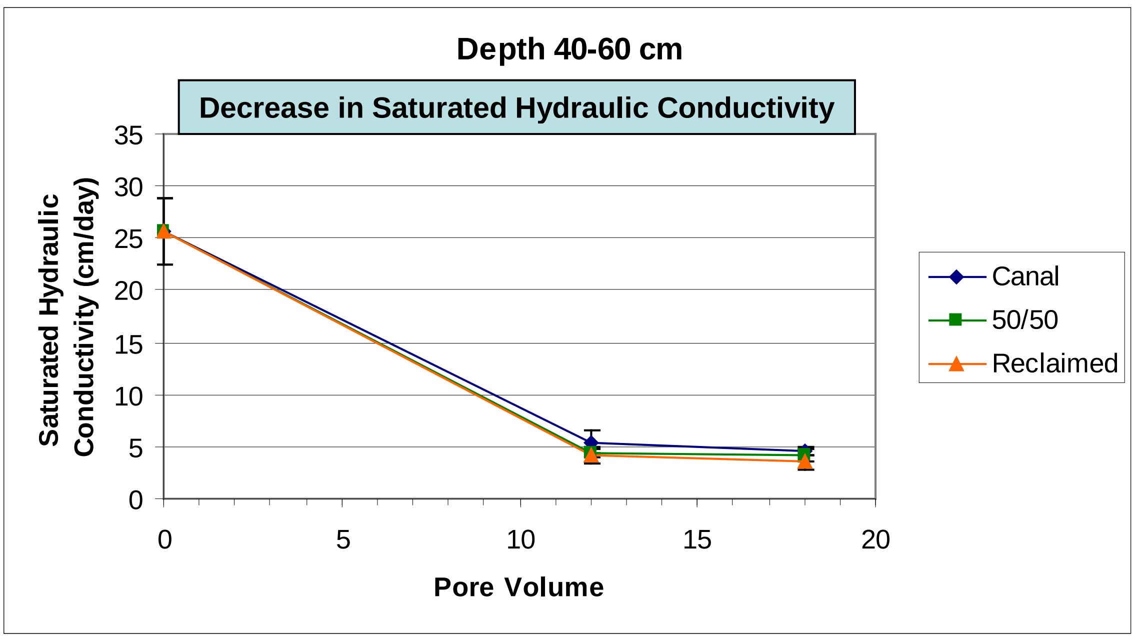
Information Transfer/Outreach Program

In the deeper horizon, depth 40-60 cm, there was no significant change in hydraulic conductivity. In this depth all treatments reduced hydraulic conductivity and the control was not statistically different from the reclaimed water and 50/50 treatment. See attached graph.

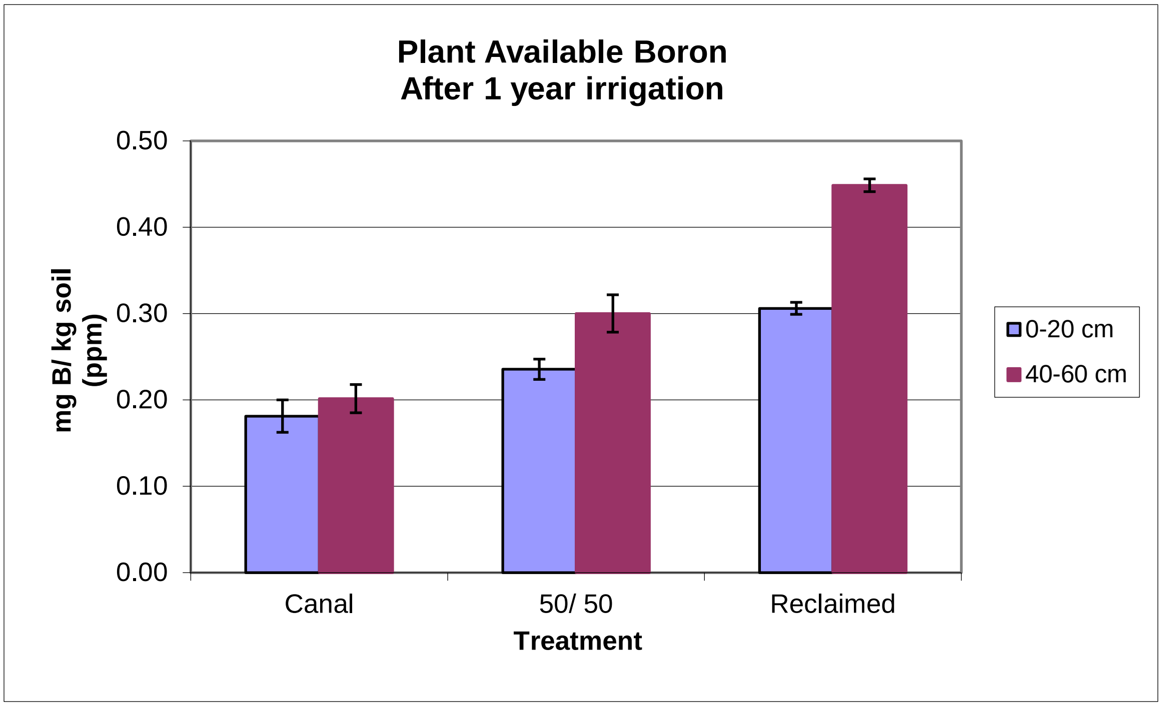
In the surface horizon, 0-20 cm, there was a significant difference in hydraulic conductivity in the reclaimed water and the 50/50 treatment when compared to the control. The Saturated hydraulic conductivity for the 50/50 treatment and the reclaimed water t



Depth 0-20 cm
Decrease in Saturated Hydraulic Conductivity
Saturated Hydraulic Conductivity (cm/day)
120
100
80
60
40
20
0
0
5
10
15
20
Pore Volume
Canal
50/50
Reclaimed



Depth 40-60 cm
Decrease in Saturated Hydraulic Conductivity
Saturated Hydraulic Conductivity (cm/day)
35
30
25
20
15
10
5
0
0
5
10
15
20
Pore Volume
Canal
50/50
Reclaimed



After one year of irrigation (1.5 m water), plant available boron concentrations in the soils were significantly higher (30 – 123% increase) when compared to the canal water control. The lower horizon, depth 40-60 cm, showed the largest increase (123%) in plant available boron concentrations in the soil for the reclaimed water treatment. Although still under the toxic threshold for citrus (0.7 ppm boron) after one year of irrigation, the reclaimed water results suggests a possible boron toxicity may occur during the second year of irrigation. A multi-year irrigation study is in progress.

The surface horizon, depth 0-20 cm, showed the greatest overall reduction in saturated hydraulic conductivity for the reclaimed and 50/50 treatment when compared to the control. All treatments showed a significant decrease in saturated hydraulic conductivity which may be due to formation of vesicular pores inside the columns. The results based on the surface horizon data suggests that farmers might have to change their irrigation practices or add gypsum to the soil if they use reclaimed water for irrigation.

Student Support table

	Total Project Funding		Supplemental Awards	Total
	Federal Funding	State Funding		
Professional Researchers	0	0	0	**0**
Masters Students	0.5	0.5	0	**1**
PhD. Students	0.5	0.5	0	**1**
Acad. Coordinator	0	0	0	**0**
Other Acad./Researchers	0	0	0	**0**
Professor/summer	0	0	0	**0**
Total	1	1	0	**2**

Publications from prior projects

Western Society of Soil Science and Western Society of Crop Science Joint Annual Meetings with the Western National Cooperative Soil Survey June 21-24, 2010
Las Vegas, NV Escalera, Julie, Dennise Jenkins. 2010 "Using Reclaimed Water for Irrigation"

ASA, CSS, SSSA 2010 Annual Meeting (Oct. 31 - Nov. 4, 2010) Long Beach, CA. Jenkins, Dennise, Julie Escalera. 2010 "Using Reclaimed Water for Irrigation."