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Original Research Article

The Impact of magnetic water treatment on salt distribution in a large unsaturated soil column

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ABSTRACT

The use of saline water for crop production leads to soil salinization. Magnetically-treated water (MTW) has been used for many years and has shown promise in leaching some ions from soil. At the same time, results have been inconsistent and somewhat controversial. In this study, we used large unsaturated columns (diameter 15 cm and length 90 cm) to determine: 1) salt distributions at depths of up to 90 cm after adding magnetically-treated, saline water to soil; 2) whether MTW could reduce the rate of accumulation of salts (measured by EC) in soil, and; 3) whether MTW could increase the leaching effect of soluble salts below root zones compared to control. The soil tested had a lower salt content compared to the water, a real-world scenario often faced when farmers elect to switch from higher-cost municipal water sources to ground water sources that have a higher saline content. Results indicated that the rate of salt accumulation was greater in the control group at the 30–60 cm depth. At the same time, the salt content at the 90 cm depth was greater in the MTW column. The results have shown that MTW changes the distribution of salts between soil layers reducing their content in the upper layers which are more important for agriculture.

1. Introduction

New technologies are needed to reduce the rate of salt accumulation and improve the leeching of salts below the root zones of salt-sensitive agricultural crops. Over time, the use of saline water for crop production leads to soil salinization. High concentrations of soluble salts accumulating in soil can significantly decrease the value and productivity of agricultural lands. Magnetically-treated water (MTW) has shown promising agricultural potential, offering a wide range of benefits, including soil desalinization. According to Yadollahpour, Rashidi, & Fatemeh (2014), MTW has demonstrated the ability to reduce water consumption and improve crop yield and plant growth. In general, the three main observed effects of MTW in soil are the removal of excess soluble salts, lowering of pH values, and the dissolving of slightly soluble components such as phosphates, carbonates and sulfates. Furthermore, the magnetic treatment of saline irrigation water is reportedly an effective method for soil desalinization (Hilai & Hilai, 2000). Mostafazadeh-Fard, Khoshravesh, Mousavi, and Kiani (2011) investigated the effects of magnetized water and irrigation water salinity on sulfate ions of soil in a field trickle irrigation experiment with a complete randomized block design. These results showed that, at all soil depths below the emitter, the levels of mean soil sulfate ions measured in the MTW treated soil were less than the non-MTW soil and the differences were significant at a 5% level. Hachicha, Kahlaoui, Khamassi, Misle, and Jouzdan (in press) also observed a significant decrease of soil salinity (EC, Na^+ and Cl^- contents) in soils irrigated with electromagnetically treated saline water compared to the soils irrigated with non-treated saline water. In contrast, compared to both treatments (control treatment and saline water treatment), the electromagnetic saline water treatment produced non-significant effects on tuber yield, Mg^{2+} and $HCO3^-$.

Soil columns have been used for many years to study hydrological properties, evaluate transport models, and monitor the fate and mobility of contaminants in soil and for evapotranspiration studies. Since 1950, a vast number of soil column-related articles have been published in the fields of hydrology, agriculture and soil science. Soil columns operating in the unsaturated regime are generally and historically referred to as lysimeters. These columns are characterized as having both air and water (or another liquid) in their pore spaces and they are typically used to reproduce conditions encountered in soil found between the earth's surface and the top of the groundwater table (Lewis & Sjostrom, 2010). A few experiments with small column sizes were conducted with MTW (Bogatin et al., 1999; Hilai, El-Fakhrani, Mabrouk, Mohamed,

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& Ebead, 2013) to evaluate the effect of MTW on the leaching of ions and salts from different saline soils. These experiments were conducted in small columns (diameter 5–8 cm; length 11–35 cm) and used high salt content soil which was higher than the salt content in the irrigation water being evaluated. No attempt has yet been made to research soil infiltration and salt accumulation in large unsaturated soil columns after MTW application, when soil has a lower salt content compared to the irrigation water, a real-world scenario often faced when farmers elect to switch from higher-cost municipal water sources to ground water sources that have a higher saline content. In this case, salt distribution should be quite different as salts from the irrigation water distribute and accumulate in the soil over time.

The objective of this study was to determine salt distribution in large unsaturated columns at depths up to 90 cm and to determine whether MTW could reduce the rate of accumulation of salts (EC) in soil and increase the leaching effect of soluble salts below root zones compared to control.

2. Materials and methods

The analyzed soil sample was collected from a 0 cm to 50 cm layer of avocado field soil in San Marcos, California. The sample was air-dried and passed through a 2 mm sieve. The sieved soil was transferred to the column using a 1-L plastic beaker according to a procedure described by Plummer, Hull, and Fox (2004); the weight of each bucket was recorded. The sediment was manually compacted in 15-cm lifts, with bulk density determined following placement of each lift. When the desired density was verified, the lift surface was scarified to avoid layering or segregation by particle size, and the next lift was placed. The columns were packed with sandy loam soil in texture with a pH of 6.5. The column was then allowed to sit open to the atmosphere for one month in the laboratory before initiation of the experiments described herein. After one month soil characteristics (EC, pH, concentration of Na, Ca, Mg, Cl, SO_4) were determined by standard methods (Bigham, 1996).

The experiments were conducted in columns made from PVC pipes (Fig. 1) that were oriented vertically and slowly saturated from the bottom with well water until they reached field holding capacity. The soil was allowed to stabilize for 24 h. The diameter of the column was 15 cm and the length was 90 cm. The column was instrumented at 30-cm intervals along its length at vertical positions denoted as levels 1 through 3. Instrumentation included three Direct Soil Conductivity Meters (HI 98331 Hanna Instruments) and three thermocouples. Leaching solution (from the same well source used to saturate the columns) was introduced into the system using a peristaltic pump to percolate through the packed soil column at a flow rate of 25 ml/min. Leaching solution was added daily at the same time for 10 min. The same leaching solution was added to both columns. However, one column was irrigated by non-MTW leaching solution and the second column received MTW leaching solution. Baseline parameters of the leaching solution are presented in Table 1. The water that passed through the columns (leachate) was collected in reservoirs under the columns. The duration of experiment was two months with two replications. Large size of columns did not allow us to set more replications in the laboratory and thus mean numbers from these two replications are presented in the article.

The MTW was applied using the Wellpure Water Treatment System (WWTS) physical water treatment device from Wellspring Water Technologies (https://www.wellspringwatertechnologies.com). This system treats water a number of ways, including magnetically (Fig. 2). The magnetic component of the system contained 16 ring- shaped, permanent, rare-earth metal magnets placed in two polycarbonate flanges oriented with their respective polarities in opposition to each other. The distance between the two flanges was 4 mm and each magnet had a 12 mm inner hole. The design forced all water moving through the system to pass through the magnets' inner holes. The magnetic field strength was measured by a

Gaussmeter Model GM-2 (AlphaLab Inc.) and it ranged from 3600 G (close to the edges) to 700 G (in the middle of the hole) for each magnet.

3. Results and discussion

Magnetic water treatment does not change chemical parameters of water. However, it changes physical parameters and according to some authors, magnetic fields have effect on reduction of surface tension, viscosity, zeta potential, solubility, and diffusion (Bogatin, 1999; Cho & Lee, 2005; Gang, St-Pierre, & Persinger, 2012; Chang & Weng, 2006). Experimental results indicated that the patterns of salt distribution (as EC) in the column irrigated with MTW leaching solution were different than those observed in the column irrigated with non-MTW leaching solution, depending on depth (Table 2). The first 30 cm of soil had less salt in the column watered by the MTW leaching solution. The same pattern was noted for soil at the 60 cm depth. The rates of salt accumulation at 0–30 and 60 cm depths are presented in Figs. 3 and 4. Linear trend lines have been added to help illustrate the general directions of the observed data points in both figures. The rate of salt accumulation was represented as the difference between the EC value at the end of the experiment and the initial EC value, divided by time (initial EC was 0.5 dS/cm). Results indicated that the rate of salt accumulation was 1.70 times greater in the control group compared to the MTW leaching solution column at the 30 cm depth and 2.26 times greater at the 60 cm depth. In addition, the salt content at the 90 cm depth in the MTW column was 1.2 times greater than control and it did not change after 20 days after reaching a steady-state condition.

A comparison of concentrations of different ions between the MTW leaching solution and control columns showed (Table 2) that sodium concentrations were 15% higher in the control column at depths of 0–30 cm and 21% higher at depths of 60 cm, respectively. The same comparison for chloride and sulfate showed that both were also higher for the control column (18% higher at 0–30 cm and 30% higher at 60 cm depth for chloride and 18% higher at 0–30 cm and 23% higher at 60 cm for sulfate, respectively). At the same time, concentrations of calcium and magnesium were practically the same for the control and MTW leaching solution columns. Similar results were obtained during a field experiment (Mostafazadeh-Fard et al., 2011) where MTW decreased concentrations of sulfate on average up to 37.3% ($p < 0.01$). Hachicha et al. (in press) showed that significantly less $Na+$ and Cl^- was found in soil irrigated with treated saline water.

Moreover, compared to control, in that study MTW had a non-significant effect on magnesium and bicarbonate contents in the soil. In addition, his data showed an increase in potassium, calcium and sulfate in soil irrigated with both treated and non-treated saline water compared to control.

It is known that sodium and chloride are some of the most undesirable ions in soil as they have very strong negative impacts on plant growth and yield. This is particularly true with avocado.

trees which are unusually sensitive to salinity, chloride, and sodium when compared to other plant species. To escape sodium and chloride accumulation most growers periodically use low salt content water to leach salts below root zones. Our soil-column experiment indicated that the magnetic treatment of saline leaching solution had an effect on EC accumulation. The rate of