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Irrigation with water containing salts: Evidence from a macro-data national case study in Israel

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ABSTRACT

Israel has an historic policy of providing marginal quality water, containing relatively high concentrations of salts, to agriculture for irrigation. Development of supply of recycled wastewater and precise, efficient field scale irrigation application technologies are hypothesized to have caused steady increased exposure of irrigated soils and crops in Israel to salinity. Nation-wide scale consideration of the effect of historical increased salinity is presented. Data was collected from laboratories used by growers for analyses of salts in soils and diagnostic leaves. Additionally, the sodium level of edible plant material in fresh produce found today in Israel was evaluated. The data suggest that the exposure of Israeli agriculture to salinity is troublesome. The leaf and soil analyses indicate a steady increase in salinity. The Na analysis of fresh produce insinuates that Israeli agricultural crops are exposed to salinity that is markedly greater than that globally acceptable. This, together with the inherent need for leaching when irrigating with water high in salts, strongly suggests that Israel's historical practice of providing marginal quality water to agriculture is not sustainable. The turn to desalination as a strategy for water security is a positive opportunity to correct the apparent mistakes of the last decades and to reverse the trends of increasing exposure to salts.

1. Introduction

Global requirements for increased food production coupled with limited and declining sources of good quality water have stimulated utilization of marginal to low quality water sources for irrigation of crops. While no absolute definition of water quality exists, mainly due to the multitude of possible traits and contaminants found within, water considered marginal or low quality almost universally contains relatively high concentrations of dissolved salts.

Irrigation with water containing high concentrations of salts allows intensive, productive crop cultivation in dry areas with lowered cost and less competition for water with municipal and industrial consumers. This comes, though, with a known weighty price, mostly to the environment, due to the need to leach salts from the root zone. With relatively sensitive crops and water of relatively high salinity, the portion of irrigation water used to move salts out of the root zone can reach more than 50% of the total volume applied (Ben-Gal et al., 2008; Dudley et al., 2008). Even with this leaching, irrigation with marginal water exposes soils and crops to salts. Exposure to salts (multiplication of concentration and time) and their accumulation in soil is known to negatively affect soil characteristics (Abrol et al., 1988; Segal et al., 2011), plant functioning (Bernstein, 1975; Raveh, 2012), and to lead to uptake and accumulation of plant-toxic ions such as sodium (Na) and chloride (Cl) in crops (Munns, 2002; Raveh, 2005). Negative effects have been well documented on plant and field scales, but large scale evaluation of salinity status or effects of exposure to salts are hard to detect, at least before critical, damaging levels are reached.

Water consumption from all sources and for all sectors in Israel increased from 230 mcm (million cubic meters) in 1948 to 1997 mcm in 2002; only 82% of the present amount is annually renewable. The remaining water supplied must be derived by groundwater mining, through the use of reclaimed wastewater, or by desalination. Whereas per capita consumption in the domestic and industrial sectors has remained essentially the same over the years, today, per capita water available for agricultural uses is less than half its volume from the 1960s. Despite the reduction, agricultural production per capita today is more than 150% of that produced 40 years ago, reflecting a threefold increase in water productivity (Ben-Gal, 2011).

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The national water carrier (NWC) conveys water from the Sea of the Galilee in the north to points south in Israel, seasonally mixing it on the way with various ground and flood water sources. Average EC (electrical conductivity) of the NWC water has historically ranged from 0.8 to 1.1 dS m^{-1}. Freshwater use in agriculture has dropped from 950 mcm in 1998 to around 550 mcm today. Total water to agriculture has been maintained via the utilization of brackish and recycled sewage water. Israel's agriculture directly uses some 80 mcm of brackish groundwater with EC of more than 2 dS m^{-1} for irrigation. Israel has made wastewater recycling a central component of its water management strategy. A master plan presented in 1956 envisioned the ultimate recycling of 150 mcm of sewage, all of which would go to agriculture. Today three times that level is recycled, representing more than 60% of all domestic wastewater produced. Effluents (treated wastewater) today contribute roughly a fifth of Israel's total water supply and a far higher percentage of the irrigation supply for agriculture. Salinity of recycled wastewater, depending on its type and origin, can range dramatically (Marcar et al., 2011). Salinity increases as the wastewater stream proceeds from sewage to treatment plants to storage facilities to effluent. In Israel, municipal recycled wastewater reaches EC of ~1 to more than 3 dS m^{-1} (Tarchitzky et al., 2006).

Recently the trend of ever increasing salinity of irrigation water in Israel is reversing. Starting in 2008 Israel has added desalinated sea water to its water distribution stream. Desalination currently provides around 30% of Israel's total water supply, often incidentally bringing very good quality water (EC < 0.4 dS m^{-1}) to agricultural areas, and consistently reducing the salinity of recycled waste water (Yermiyahu et al., 2007).

Other important technological advances occurred in Israel over the past several decades, with the most notable surely being drip irrigation. Irrigation during this time switched from gravity-based flood and furrow to pressure based sprinklers and drip systems. Today all of Israel's orchards and a large percentage of field and vegetable crops are micro-irrigated with drippers, micro-sprinklers or other point based emitters. The wide-scale adoption of low-volume irrigation systems (e.g., drip, micro-sprinklers) and automation has increased the average efficiency (relative amount of water utilized by crops) to 90% as compared to 64% for furrow irrigation or 75% for sprinklers. Development of drip irrigation technology that allows low-flow application of water uniformly throughout agricultural fields, along with the application of this technology in agricultural water management, has been a cornerstone in Israel's advancements in water use efficiency. In addition, a significant advantage of drip-irrigation systems lies in their ability to supply nutrients as well as water (Ben-Gal, 2011).

We present nation-wide scale consideration of the effect of historical increased exposure to crops in Israel to salinity. We collected and present data from laboratories used by Israeli growers concerning analyses of salts in soils and diagnostic leaves from citrus orchards. We additionally look at the Na level of edible plant material in produce found today in Israel.

2. Materials and methods

Two databases were mined to explore trends in salinity. The first contained ~3000 soil samples (sampled from the upper 90 cm soil layer) that were collected by Israeli growers between 1995 and 2011. The samples were sent to national laboratories for soil electrical conductivity (EC) and sodium adsorption ratio (SAR) analysis, using soil saturated paste extract (Page et al., 1982). The second database summarized ~30,000 citrus leaf samples (4 to 6 month old leaves from fruiting branches) tested for Na and Cl concentration between 1993 and 2011 (list of varieties and orchard location are presented in Raveh, 2013). The leaves were washed in distilled water, oven dried at 65 °C for 72 h, pulverized and analyzed for Cl and Na, using water extract (Raveh, 2005). Both databases included samples from all parts of the country. Since growers generally do not request SAR, EC, leaf Cl and Na analysis for orchards that appear healthy, it is likely that the mean values found over the years in the databases do not necessarily represent absolute mean nationwide values. Assuming that the samples represent more problematic areas than not, the values for all of the parameters tested are likely to be higher than actual averages. While actual annual rainfall in Israel fluctuates widely, during the period that the samples were taken, the average annual rainfall in Israel did not change (Ziv et al., 2013).

In order to assess a more current picture of the state of salinity in Israel, 650 samples of 26 different fruits and vegetables (25 samples of each product) were acquired from all over Israel during 2012. The edible part of each product was frozen (−20 °C), milled with a tissue homogenizer and filtrated (Whatman filter paper 40). The Na concentration of the filtrated extract was measured with a flame photometer (Corning model 410). The Na of Israeli crops was compared to those found in the USDA National Nutrient Database for Standard Reference Food and Drug Administration (U.S. Department of Agriculture, National Nutrient Database for Standard Reference, Release 27, http://www.ars.usda.gov/nutrientdata Accessed 27 Oct 2015).

3. Results and discussion

The total number of annual soil samples varied from 212 to 1209 and total annual leaf samples ranged from 110 to 985. Average number of leaf samples increased from 421 in the first years of database (1993–1997) to 600 in the final years (2007–2011). Geographic distribution of samples shifted northwards over time with 63% of leaf samples originating in the south of the country (Ashkelon to Tseelim), 32% in the center (Haifa to Ashdod) and 5% in the north (Galil, Golan and Jezreel Valley) in the first years changing to 39% originating in the south, 39% in the center and 22% in the north in the final years represented.

Average soil SAR in samples sent to the lab by growers increased over the last two decades by 50%, from values of 6 to 9 (Fig. 1A). For the same samples, soil EC remained fairly constant at around 5.5 dS/m (Fig. 1B). This phenomenon has been documented on a field scale in experimental work comparing long term irrigation with recycled vs fresh water (Lado et al., 2012; Segal et al., 2011).

Segal et al. (2011) showed for olives that while winter rains leached total soil salinity to base levels annually, irrigation with recycled wastewater, relatively high in dissolved salts, lead to steady increases in SAR. The high soil sodicity due to high Na relative to Mg and Ca is not necessarily problematic in itself but, the combination of high soil SAR and low salinity water (e.g., rain) can lead to soil physical deterioration due to dispersion of clays and disturbed water infiltration and distribution. Sodic soils can be reclaimed using gypsum or limestone amendments (Abrol et al., 1988).

Citrus leaf analysis reveals that during the same time period, Cl and Na concentrations in samples sent by growers increased by ~200% (Fig. 2A and B). Average annual leaf Cl increased from 0.26% DW to 0.53% DW while leaf Na increased from 0.12% DW to 0.20% DW. Chloride is toxic to plants and Na, while sometimes appearing beneficial at small concentrations, becomes toxic at higher levels as well (Bloom, 1998). The concentration levels of Na and Cl in citrus leaves found in the current survey are well under the standards considered toxic in citrus for Na (0.24% DW) and just reached the toxicity level (0.50% DW) for Cl (Raveh, 2005). Yet, the fact of steady increase is notable for both elements.

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