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Assessing the suitability of saline wastewaters for irrigation of *Citrus* spp.: Emphasis on boron and specific-ion interactions

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ABSTRACT

Many ground waters and recycled municipal wastewaters contain elevated concentrations of boron (B) and salts but are nonetheless potential irrigation water sources for agricultural production. Unlike most agricultural crops, *Citrus* spp. is among the most sensitive to B and salinity. Here, an extensive review of the literature from 1928 to present on *Citrus* spp. tolerance to B and specific ions has been conducted. The overall suitability of such water supplies largely depends upon the salt and B concentration in the irrigation water, irrigation management, rainfall, soil and climatic conditions and orange rootstock. Since salinity and B stresses often occur together, the overall suitability may depend on interactive abiotic stresses as well. The combination and potential interaction of these constituents, combined with the soil and climatic conditions, can affect the overall suitability of B in irrigation water over the long-term. And there is evidence of internal tolerance mechanisms (i.e. B transport/compartmentation; B complexation) present allowing leaves to tolerate higher B concentrations than they would otherwise and that certain amendments can reduce uptake and transport from rootstock to scion. Regardless, new research does not provide any more information to suggest that the existing B tolerance guidelines for orange (0.50–0.75 mg/L in the soil solution, Bss) should be adjusted upwards or downwards. The challenge comes in determining the maximum B concentration in the irrigation water (Bw) that would result in these Bss tolerance values. Two steady-state approaches that were used here suggest that the maximum Bw for the protection of orange falls between 0.3 and 0.5 mg/L over the long term provided good water management, adequate leaching and no additional stresses are affecting the tree. For lemon, maximum Bw concentrations would be less. The presence of specific ions and ion interactions makes water quality assessment difficult.

1. Introduction

The use of recycled wastewaters (RWW) to irrigate agronomic and horticultural crops, as well as golf courses, parks and plants in ornamental landscapes, has gained considerable interest over the years. One major driving force is the uncertainty of the allocation and dependability of good quality water in the future as competition among agricultural, urban, industrial, environmental, and recreational uses continues to increase. Faced with less dependable supplies of good quality water, these users now turn to recycled waters as a valuable alternative and are continuing to develop innovative plant and water management strategies to mitigate the adverse effects of salt and specific-ion stresses these poor quality waters may impose on plant growth, yield, and quality. Use of RWW has considerable potential as a sustained future-supply of supplemental irrigation water, increasing dramatically in many arid and semi-arid climates all over the world including China, the Middle East, Mediterranean countries, Australia, North and South America and Africa.

In these same climates, *Citrus* spp. is a major crop and is a good candidate for RWW since there is an adequate separation between the fruit above the ground and irrigation water delivery systems at the soil surface. This reduces the chances of pathological contamination but the inorganic water quality characteristics of the treated wastewater could limit its potential for this salt and boron (B) sensitive crop. But, as farmers have been approached about potentially transferring to RWW to conserve precious water resources for urban, recreational and environmental users, concerns have been raised about using that water because it contains higher concentrations of B and salts than the water sources traditionally

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used. Research suggests that certain elevated concentrations of B can injure trees, impact fruit production, and affect fruit quality. Although B is a required nutrient for crops, there is a small concentration range between that level which is considered adequate or optimal for crop production and that considered toxic (Grieve et al., 2012). Boron present in any water source can accumulate in soil, similar to salinity and minerals. However, unlike common salinizing salts, B has a higher affinity for the soil. Therefore, a lag time exists both in terms of the time it takes B concentrations to increase in the soil water and the time and amount of water it takes to reclaim soils once they become B-affected.

Studies have shown that *Citrus* spp. is one of the most sensitive crops to B and that tolerance varies among *Citrus* species and rootstocks (Grieve et al., 2012). However, many of these research studies upon which current water quality guidelines are based, were conducted over 60 years ago. Although these studies are scientifically sound and continue to be cited regularly in the literature, additional studies have been conducted more recently. Therefore, a comprehensive review is needed where older literature is synthesized along with new published information.

The intent of this review is to conduct a comprehensive review of the literature to evaluate the impacts of B on *Citrus* spp. with particular emphasis on orange (*Citrus sinensis* Osbeck) and to assess the maximum concentration of B in RWW that can safely be used for irrigation of orange trees over the long term. The assessment will emphasize potential long-term impacts and will address best management practices needed to optimize RWW use. This study will also identify potential ion interactions and unknowns that suggest research directions that will help fill those unknown gaps in knowledge.

2. Use of recycled waste waters for irrigation of citrus: case studies

Successful use of RWW, at least over several years, has been demonstrated in Egypt, Greece, Israel, Italy, Jordan, Portugal, Spain, Tunisia, and the United States (Pereira et al., 2011; Pescod, 1992). Israel is perhaps one of the pioneering countries in use of RWW where about 80% of the total recycled water is reused for irrigation (Feigin et al., 1990; Lado et al., 2011). In Egypt, RWW was used to irrigate *Citrus* spp. for up to 60 years without adverse effects on tree growth (Omran et al., 1988). In Jordan, treated wastewater from the city of Amman's Al-Samra treatment plant is blended with water in the King Talal reservoir and is used for unrestricted irrigation in the Jordan valley (Grattan, 2000), much of which is planted to *Citrus* spp.

In the United States, RWW has been successfully used to irrigate citrus (sweet orange and grapefruit) in central Florida for about 25 years. These findings come from an extensive study (Water Conserv II) by the city of Orlando and surrounding Orange and Lake Counties (Morgan, 2011; Morgan et al., 2008). Despite growers' initial reluctance to use this water, not only did this RWW not affect crop production or quality, it reduced the fertilizer requirement, including B. Even though RWW increased tissue sodium (Na), chloride (Cl), and B levels above that when conventional water was used, concentrations remained below toxic levels. The success is largely attributed to well-drained soils and high annual rainfall in Florida (>1200 mm). Both these factors promote adequate leaching. In southern Florida, *Citrus* spp. was irrigated with RWW (0.31 mg B/L) for 11 years (Pereira et al., 2011). Concentrations of B steadily increased in leaves over the years at a rate of 4.6 mg B/kg dry weight per year even though leaf concentrations remained far below toxic levels. However, at this rate of accumulation, leaf B concentrations would exceed 200 mg B/kg (approaching the potentially toxic zone) after 30 years.

Salinity and B in the recycled water, however, can limit its long-term potential for reuse. In southern Portugal, young orange trees were budded on to 'Troyer Citrange' rootstock and drip irrigated with treated wastewater (Costa et al., 2012). The soil was fine textured (silt to clay loam soil) with a hard pan 1 m deep. The irrigation water was saline (3.6 dS/m equivalent) with a Cl concentration of 923 mg/L and treatments continued for 2 years. The B concentration was not indicated in the report but, due to poor soil drainage, the investigators did find an increase in soil salinity and Cl, which will likely have long-term impacts. In Murcia, Spain, B (0.8 and 1.4 mg/L) and Cl (170 and 221 mg/L) were limiting constituents for the long-term use of municipal wastewater for irrigation of lemon (Pedrero and Alarcon, 2009). In another study in Murcia with mandarins (Pedrero et al., 2012), trees were irrigated with RWW containing 0.6–0.9 mg B/L and had an electrical conductivity (EC) of 3 dS/m. Even though tissue levels were kept below toxic levels, leaf B concentration increased by 75% in just 2 years. Boron concentrations also increased in *Citrus* spp. leaves in orchards irrigated with RWW in southern Spain after 3 years but remained below toxic levels due to the short duration of the study (Reboll et al., 2000). These studies suggest that B, salinity, and Cl can limit the long-term feasibility of using RWW to irrigate *Citrus* spp.

3. Literature review on citrus response to salinity and specific ions

All irrigation water contains inorganic constituents, primarily dissolved salts, but these salts vary in both concentration and composition. The major constituents of dissolved salts are the cations, which include sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}), and anions, which include chloride (Cl^-), sulfate ($SO_4{}^{2-}$) and bicarbonate ($HCO_3{}^-$). Collectively, these ions in solution conduct electricity so that the concentration of salts is linearly related to the EC of the water. The EC can be reported in terms of the irrigation water (ECw), the soil water (ECss) or the saturated soil extract (ECe).

There are other important constituents in water as well but they exist in concentrations much lower than these main ions. One of the constituents in irrigation water that exists at much lower concentrations is B where irrigation waters typically are less than 1 mg/L, but can exceed several mg/L in some areas. Unless the pH of the water is high, the majority of B exists in the water as boric acid ($B(OH)_3$). It is in this undissociated form that most of the B is absorbed by the roots (Marschner, 1995).

Although many of the constituents mentioned above are required nutrients by the crop, they can be growth limiting when concentrations in the root zone exceed critical levels. These critical levels vary among crops.

Citrus spp. responds not only to salinity but to specific constituents in the water as well (Ferguson and Grattan, 2005; Läuchli and Grattan, 2012a). Researchers have therefore classified these responses to salinity as either 'osmotic' or "specific ion" effects. Osmotic effects occur because of the concentration of salt in the soil solution, with no particular reference to the kind of salts present. Therefore, fertilizer salts can suppress *Citrus* spp. growth as can table salt. Specific ion effects, on the other hand, occur due to specific ions (i.e. Cl, Na and/or B) that accumulate in the plant causing specific injury to metabolic processes and tissue. Although it is difficult to quantify the contribution of growth suppression by either 'osmotic' or 'specific ion' effects, researchers have found growth suppression in *Citrus* spp. without observing injury symptoms. Therefore, it is generally believed that 'osmotic' effects are the dominant growth suppressing effect (Dasberg et al., 1991; Maas, 1993). Nevertheless, salinity is cumulative (Levy and Syvertsen, 2004) and ion toxicity can become the dominant stress over the long-term.