Effects of saline reclaimed water irrigation and regulated deficit irrigation on fruit quality of citrus in mid-long term

CRISTINA ROMERO-TRIGUEROS*[1,2], JUAN JOSÉ ALARCÓN CABAÑERO[1], PEDRO ANTONIO NORTES TORTOSA[1], JOSÉ MARÍA BAYONA GAMBÍN[1], JOSÉ FRANCISCO MAESTRE-VALERO[3], EMILIO NICOLÁS NICOLÁS[1]

* Corresponding Author: Romero-Trigueros, C.: cromero@cebas.csic.es; c.romerotrigueros@uniba.it

[1] Department of Irrigation, Centro de Edafología y Biología Aplicada del Segura (CEBAS-CSIC), Campus Universitario de Espinardo, PO Box 164, 30100, Murcia, Spain. Telephone +34 968 396200

jalarcon@cebas.csic.es

panortes@cebas.csic.es

jmbayona@cebas.csic.es

emilio@cebas.csic.es

[2] Present address: Department of Agricultural and Environmental Science, University of Bari "Aldo Moro", Campus, Via Amendola 165/A, 70126, Bari, Italy.

[3] Department of Food Engineering and Agricultural Equipment, Escuela Técnica Superior de Ingeniería Agronómica, Polytechnic University of Cartagena, Paseo Alfonso XIII, 48, 30203, Cartagena, Spain.

josef.maestre@upct.es

Abstract

BACKGROUND: Saline reclaimed water (RW) can become a valuable irrigation water source in semiarid regions although its long-term effects on the quality of citrus are little known. We evaluated the fruit quality response of mandarins and grapefruits to RW combined with control (C) and regulated deficit irrigation (RDI) during eight seasons (2008-2015). RESULTS: RDI strategy improved juice quality due to an increase in soluble solid contents (SSC) in both species. RW irrigation (C or RDI) in mandarin resulted in an increasing trend fruit weight and, on the contrary, in a reduction of maturity index (MI) in RW-C fruits owing to titratable acidity increased to a greater degree than SSC; nevertheless, quality standards were satisfied. The grapefruit rootstock (*Citrus Macrophylla*) enhanced salinity resilience and, hence, MI was not affected. CONCLUSIONS: Thus, long-term feasibility of using RW and RDI to irrigate citrus was demonstrated. However, they must be performed cautiously to avoid damaging fruit quality caused by phytotoxic elements.

Keywords: fruit weight; grapefruit; mandarin; maturity index; organic acid; soluble solid content.

1. Introduction

The worldwide use of reclaimed water (RW) has developed very rapidly, mainly in arid and semi-arid climates. Currently, approximately 4% of all RW is reused in the world. It is foreseen that, by 2030, RW will represent 1.66% (26 billion m^3 per year) of the total water use[1]. Specifically, in Murcia, a semi-arid region located in southern Spain, there are 93 operating waste water tertiary plants delivering almost 109 hm^3 per year[2].

The agriculture is the largest consumer of water resources and is a major economic sector in many countries. There is an important restriction on water for agriculture mainly ruled by population growth and specifically the trend towards irrigated agriculture[3]. In that regard, the use of RW for irrigation has gained importance during the last two decades. In fact, agricultural irrigation is the main application for water reuse globally. For the last five years, agriculture has comprised nearly 70% of global water consumption[4].

RW has great potential to become, with appropriate management, a valuable irrigation water source. RW positively influences plant nutrition by rendering the concentration of macro nutrients, i.e. N, P, K closer to their optimum levels for plant growth and that might also reduce fertilizer application rates[5]. Using routine fertilization regimes not considering nutrients delivered with the RW might expose plants to excess levels of the macronutrients N, P and K[6] or increase the lost in the ecosystem through leaching[5].

Nevertheless, the use of RW may have risks for agriculture since it often has salts concentration higher than that found in natural water resources: imbalanced supply of micro-nutrient in RW may cause nutritional excess of any of them, including Mn, Zn, Cu, B, Na and Cl^- [7]. Salinity is especially a problem for citrus, which have been classified as a salt-sensitive crop[8]. The negative effect of high salts and B levels on fruit quality and on citrus trees production and growth, contributing to the yellowing and defoliation of trees, is related mainly to their gradual accumulation to toxic levels in the root zone[9] or in leaf tissues[10] rather than the osmotic changes [11]. In this sense, just few studies have evaluated the long-term effects of using saline RW. For instance, [10] they highlighted that after five years of irrigating a grapefruit orchard with saline RW with an electrical conductivity, EC, ≈ 3 dS m^{-1}, trees showed negative effects on plant physiological performance and on yield. Other studies also suggest that B and salinity can limit the feasibility of using RW to irrigate *citrus* [5, 12-16].

Despite these negative agronomic results by using RW in *citrus*, some studies have proved the technical and agronomical advantages; however, most of them either used RW with low EC below harmful thresholds for citrus trees, ([17] with EC ≈ 1.10 dS m^{-1} and [7] with EC ≈ 0.99 dS m^{-1}), or the study area was with well-drained soils and high annual rainfall as Florida [7, 18, 19], or the effect of reusing saline RW was only evaluated in the short-term (experiments from several weeks up to about three seasons). [20]They found that grapefruit trees, grafted on *Swingle citrumelo* rootstock and irrigated for three years with RW (EC ≈ 1.80 dS m^{-1}), with or without fertilizer, had larger canopies and fruit yield than trees irrigated with well water (EC ≈ 0.35 dS m^{-1}). [21]They irrigated a young grapefruit orchard with saline RW (EC ≈ 3 dS m^{-1}) for three seasons and did not observe any significant reductions of vegetative growth or yield.

Regarding citrus quality, sugars and organic acids are major primary metabolites in the citrus juice and are important components for fruit internal quality. The contents of sugars and organic acids and their ratios (sugar content/acid content) affect the taste of citrus fruit[22]. However, information on the effects of saline water on the fruit quality in *citrus* is scarce and most of it comes from experiments in which salt does not belong directly from the water source, as in RW, but it is injected into the system from a concentrated NaCl solution to obtain the saline treatment[23-26].

Moreover, the use of deficit irrigation strategies, as regulated deficit irrigation (RDI) where water deficits are imposed only during the crop developmental stages that are least sensitive to water stress, is becoming a common practice in areas with low water availability[22]. Some works show RDI affect the yield quality[26,27], however, there are no studies about the effects of combined use of saline RW and deficit irrigation strategies.

Study presented here is specifically related to the long-term viability of using saline RW and deficit strategies to irrigate grapefruit and mandarin trees (2008- 2015) and the effect of these treatments on fruit quality parameters as peel thickness, fruit weight and organic acids and sugars which are among the major compounds of citrus fruit pulp and their concentrations largely affect taste characteristics and organoleptic quality[28].

We hypothesize that RDI strategy can result in an improvement in yield quality due to increases in soluble solid content in juice. On the contrary, saline irrigation (RW) can affect negatively fruit quality in a medium-long term, mainly in mandarin trees since the rootstock used (Carrizo Citrange) is more sensitive than the rootstock used in grapefruit trees (*Citrus Macrophylla*).

2. Materials and methods

2.1. Experimental plot and irrigation treatments

The experiment was conducted from 2008 to 2015 at a 1 ha orchard located in Campotéjar-Murcia, south-eastern Spain (38º07´18´´ N; 1º13´15´´ W) cultivated with 2 crops. One crop consisted of mandarin trees (*Citrus clementina* cv. 'Orogrande') planted in 2000 grafted on Carrizo Citrange (*Citrus sinensis* [L.] Osb. × *Poncirus trifoliata* [L.]) rootstock. The other crop consisted of 'Star Ruby' grapefruit trees (*Citrus paradisi* Macf) grafted on Macrophylla rootstock [*Citrus Macrophylla*] planted in 2005. All mandarins were considered adult trees from 2008-2015 period. However, in the case of grapefruit, two periods based on trees development throughout the eight year experiment were established: young (2008-2010, up to 6 years-old) and adult trees (2011-2015). This area is characterized by a Mediterranean semi-arid climate with warm, dry summers and mild winter conditions. The average annual reference evapotranspiration (ET_0) and rainfall is 1326 and 300 mm, respectively. For each crop, a total of 32 trees were used (8 trees per treatment). The experiment was laid out in randomized blocks with 4 replications per treatment. Each replicate consisted of 3 rows with 4 trees each and the two trees in the center of the middle rows were used for measurements and the rest acted as buffer rows.

With respect to irrigation treatments, two water sources were used for both crops. The first one was pumped from the Tajo-Segura canal (fresh transfer water, TW, EC ≈ 1 dS m^{-1}) and the second one was pumped from Molina de Segura tertiary WWTP (reclaimed water, RW). This source was automatically blended at the irrigation control-head with water from the canal to maintain its EC value ≈ 3 dS m^{-1}, which is above the threshold for significant yield losses (EC ≈ 2 dS m^{-1}) in citrus trees[29]. Two irrigation treatments were established for each water source: i) control (C) irrigated to fully satisfy crop water requirements (100% of crop evapotranspiration, ET_c) and ii) regulated deficit irrigation (RDI) which received half the water amount applied to the C (50% ET_c) during the second stage of fruit rapid development (about the end of June to mid-September).

The irrigation doses were scheduled based on the daily crop evapotranspiration (ET_c) accumulated during the previous week. ET_c values were estimated as ET_0, calculated with the Penman–Monteith methodology[30]. All treatments received the same amounts of fertilizer N–P_2O_5–K_2O applied through the drip irrigation system. For grapefruit, in 2008 the fertilizer amounts were 122-61-88 kg ha^{-1} $year^{-1}$ and increased by about 10% each year up to 2010; from 2011 to 2015 (grapefruits were already considered adult trees) fertilizer rates were 215-110-150 kg ha^{-1} $year^{-1}$. For mandarin, from 2008 to 2015 the amounts were 215-100-90 kg ha^{-1} $year^{-1}$.

2.2. Water quality characterization

Four water samples from each irrigation source were collected monthly from 2008 to 2015. An inductively coupled plasma mass spectrometer (ICP-ICAP 6500 DUO Thermo, England) was used to determine the concentration of Na, K, Ca and Mg. Anions (Cl^-, NO_3^-, PO_4^{3-} and SO_4^{2-}) were analyzed by ion chromatography with a liquid chromatograph (Metrohm, Switzerland). EC were determined using a PC-2700 meter (Eutech Instruments, Singapore) and pH was measured with a Crison 507 pH-meter (Crison Instruments S.A., Barcelona, Spain).

2.3. Fruit quality

Each season, eight inner trees per treatment (two trees in each replicate) were evaluated to determine fruit weight. The number of picks conducted during the harvest period each year was determined by the commercial destination of fruits. Fruit quality was assessed annually by randomly collecting 100 fruits per treatment (25 fruits per block). The parameters evaluated included peel thickness (PT), soluble solid content (SSC), titratable acidity (TA) and maturity index (MI). SSC was determined with a handheld refractometer (Atago N1, Tokyo, Japan) and TA by titrating 2 g of juice with 0.1 mol L^{-1} NaOH to pH 8.1 using an automatic titration system. Finally, MI was computed as the ratio of SSC to TA. This fruit quality index is one of the most important[31] which affects the perception of taste (sweetness and acidity) by the consumer.

2.4. Statistical design and analysis

A weighted analysis of variance (ANOVA; statistical software IBM SPSS Statistics v.21 for Windows) followed by Tukey´s multiple comparison test ($P \leq 0.05$) were used for assessing differences among treatments.

3. Results

3.1. Irrigation water quality and volume applied

Overall, significant differences between TW and RW sources were observed throughout the experiment. RW had the highest salinity and sodicity with average values of EC around 3.51 dS m^{-1} and sodium adsorption ratio (SAR_w) around 7.78 [meq $L^{-1}]^{0.5}$; whereas TW had lower values, EC of 1.00 dS m^{-1} and SAR_w of 1.28 [meq $L^{-1}]^{0.5}$ (Table 1). RW also had higher concentrations of NO_3^-, PO_4^{3-}, SO_4^{2-}, K, Na, B and Cl^- than TW. It is also noteworthy that the concentrations of the phytotoxic elements Na, Cl^- and B in RW exceeded the thresholds at which detrimental effects on citrus might be observed: [32]Na > 5.02 meq l^{-1}, [29]Cl^- > 6.71 meq l^{-1} and [33]B > 0.5 mg l^{-1}.

3.2. Fruit quality

3.2.1 Mandarin crop

Significant differences between the treatments were observed for the different quality parameters in mandarin trees.

Fruit weight was significantly increased since the beginning of the assay (2008) by the irrigation with RW (C or RDI) in the mid-term (2008-2011 period) (Figure 1A). Conversely, in long term (2012-2014 period) the differences in fruit weight between such treatments were no significant due to PT was reduced significantly in RW treatments respect to TW treatments in these three years, precisely (Figure 1B). In the mid-term (2008-2011 period) there were not differences in PT (Figure 1B). Neither fruit weight nor PT were affected by deficit irrigation when trees were irrigated with TW.

As for MI (Figure 2) in mandarin trees, no significant differences were found for RW-C versus TW-C treatment in the first two years (2008-2009) and, neither, in 2014. However, in the rest of years (2010-2013 period and 2015), MI levels were significantly reduced by irrigation with saline RW mainly due to the increase in TA (significant in 2013 and 2015) was higher than that of SSC (Table 2 and 3), compared to control trees. In regard to RDI treatments, a tendency to increase both SSC and TA was observed over the years. Nevertheless, in TW-RDI there were practically no significant differences in MI respect to control because SSC and TA values were increased simultaneously; In RW-RDI, MI decreased significantly some years (Figure 2) (2010, 2012 and 2013) since TA increased proportionally more than SSC (Table 2 and 3).

In order to interpret the global behavior during all the years of assay, the average SSC and TA values of total period (2008-2015) were calculated. The SSC middle values were 8.89±0.31a, 9.42±0.43c, 9.20±0.35ab and 9.28±0.39ab for TW-C, TW-RDI, RW-C and RW-RDI, respectively. Respect to the TA, 0.80±0.03a, 0.83±0.03a, 0.90±0.03b and 0.88±0.03ab for TW-C, TW-RDI, RW-C and RW-RDI, respectively.

3.2.2 Grapefruit crop

In grapefruit, as in mandarin trees, irrigation with RW (C or RDI) resulted in a tendency to increase the fruit weight in mid-term (2008-2010, with young trees) and in 2014 (Figure 3A). Otherwise, deficit irrigation did not affect fruit weight respect control trees, except i) in 2009 that the fruits from RW-RDI increased their weight, since the crop load was lower, and ii) in 2010 (both RDI treatments) and 2015 (RW-RDI) that it was decreased although it did not affect yield nor crop load (data not showed).

Regarding PT (Figure 3B), an increasing trend was observed in the RW treatments with respect to the TW during the first stage at mid-term (2008-2010, with young trees), although such differences were only significant in 2008. This was directly related to the increase in fruit weight observed in that same period (Figure 3A). Then, during the 2011-2013 period, neither RW nor RDI affected such parameter. Nevertheless, when the PT average value of the three last years (2013-2015, with adult trees) was calculated, we observed by a two-way ANOVA analysis using water source and water amount as main factors, that salinity from RW resulted in a decreasing PT.

MI did not show a clear trend (Figure 2). Whether analyzing season by season we observed alternate behavior in both mid and long-term: in 2009, 2011, 2013 and 2015 there were no significant differences between treatments; however, in 2008, MI decreased in RW-C treatment and in 2010, 2012 and 2014 increased in RDI treatments (2012 in RW-RDI and 2010 and 2014 in TW-RDI). These changes were associated with a decrease or an increase in only SSC, since TA did not vary between treatments practically over the eight years (Tables 2 and 3).

As has been mentioned in mandarin, we determined the average SSC and TA values of total period (2008-2015) in order to interpret the global behavior. SSC middle values were 11.95±0.37a, 12.56±0.46b, 11.91±0.42a and 12.46±0.40b for TW-C, TW-RDI, RW-C and RW-RDI, respectively. Respect to TA, 1.98±0.11a, 1.99±0.15a, 2.08±0.15a and 2.06±0.14a for TW-C, TW-RDI, RW-C and RW-RDI, respectively.

4. Discussion

4.1 Mandarin response to irrigation with RW and RDI

In our study, the increase in mandarin weight due to the RW irrigation was associated with a decrease in crop load (number of fruits per tree) (data not shown). Moreover, the fact that PT (epicarp and mesocarp thickness) decreased in some year without a significant reduction in fruit weight respect to TW-C indicated that the endocarp thickness likely increased, resulting in a higher juice content, as we observed in RW treatments (data not shown). [27]Other authors evaluated the responses of 'Clemenules' mandarin grafted on 'Cleopatra' mandarin rootstock to irrigation with saline water in the short-term (3 years) and they did not detect changes by salinity on i) PT, as in the first years of our work, and on ii) fruit weight, contrary to our results, being justified by the different rootstocks used.

The increase in TA that resulted in a decrease in MI levels by irrigation with saline RW was according to [27], who found that the MI decreased due to an increase in TA in the first year of the experiment.

The tendency to increase both SSC and TA observed in RDI treatments over the years was also reported by others authors who reported an increase in TA and, mainly in SSC, as a result of water deficit applied in mandarin trees grafted onto Cleopatra mandarin[34] and in Clementina de Nules grafted on Carrizo Citrange[35].

4.2 Grapefruit response to irrigation with RW and RDI

The increase in the peel thickness showed in the RW treatments was similar to those presented by[27] who determined the responses of a Star Ruby grapefruit orchard grafted on Cleopatra rootstock to irrigation with saline water in the short-term (3 years), and detected an increase in PT.

We did not found a significant trend as for the index maturity, in spite the TA did not vary between treatments practically over the eight years. Our results were not in agreement with those found in[27], who detected clearly an increase in SSC and TA in the three years irrigated with saline water. These different results might be explained by i) the different rootstocks used, which have probably different physiological resilience to salinity stress, (ii) a higher level of water stress was reached, with stem values below -2.0 MPa, compared to the values above -1.0 MPa observed in our study (data not shown). Besides, it was reported, in \`Marsh´ and ´Ray Ruby´ grapefruits on Sour Orange, Swingle Citrumelo and Carrizo Citrange rootstocks, a slight increase in SSC, sometimes accompanied with a similar increase in acidity, which caused most times the MI remained unchanged[23].

The increase of SSC and TA in citrus fruits can improve the internal fruit quality since these parameters influence the taste of the fruit[25,26,36]. However, this effect has different connotations, depending on whether we consider mandarin or grapefruit fruits. In mandarin, the increase in SSC and TA could be considered as an improvement in the fruit quality, since in semi-arid conditions, it is typical that mandarin fruits have low TA[25]; thus, the increase in both SSC and TA caused by the RDI treatments in our study—without altering the MI—could improve the fruit taste. However, under Mediterranean conditions, grapefruits have usually a high TA[27]; so, if salinity increases the TA even more, the fruits become too acid, affecting negatively the acceptance of grapefruit by the consumer[37]. Fortunately, during the 8-year of our assay TA has not been affected by any treatment in grapefruit under young or adult trees in a mid and long term. This result is important since grapefruit juices are produced by industries based on its taste[38].

4.3 Both species

RDI resulted in an improvement in yield quality due to increases in SSC in both species. On the contrary, saline irrigation (RW-C) affected more negatively the MI of mandarin than grapefruit since the rootstock used in grapefruit (*Citrus Macrophylla*) improved salinity resilience. Knowledge of the relative salt tolerance of rootstock citrus is critical for growers, because only those citrus plantations with salt-tolerant will be sustainable[27].

In addition, fruits from all treatments satisfied the quality standards proposed by UNECE[39]: minimum sugar/acid ratio 7.0/1 for mandarin and minimum sugar content > 8 ºBrix for grapefruits.

5. Conclusions

In drought-prone regions, as southeast Spain, salinity and water scarcity are serious problems in citrus orchards. In this sense, RW can become a major potential source for irrigation.

In this long-term study, effects of irrigation with saline RW and water deficit have been detected on the fruit quality of mandarin and grapefruit.

On mandarin, several positive issues were observed i) RW irrigation resulted in an increasing trend on fruit weight with respect to TW since the beginning of the assay, although such differences were not significant in 2012, 2013 and 2014 due to a decreasing on peel thickness; ii) RDI treatments (RW or TW) increased SSC and TA levels in long-term. On the contrary, one negative aspect was found: RW was associated to a reduction in MI owing to the TA increased to a greater degree than the SSC. Nevertheless, fruit from this treatment satisfied the quality standards proposed by UNECE[41] during the eight years of the trial.

On grapefruit, we highlight three aspects i) an increasing trend in SSC resulting to an improvement in MI in RDI treatments, although such differences were significant in alternate years: 2010, 2012 and 2014; ii) neither RDC nor RW increased the fruit acidity; iii) a significant decreasing in PT in the last two years.

This study shows the long-term feasibility of using saline RW and deficit irrigation strategies in the fruit quality of mandarin and grapefruit species. However, despite this, irrigation with RW must be performed cautiously as it will only be successful with irrigation management measures and intensive monitoring. In addition, it is interesting to continue this study more years to determine further long-term effects on crops of the use of saline RW combined with RDI strategies. To our knowledge, this is the first study that compares in the long term fruit quality parameters in *citrus* with irrigation water of different quality (RW and TW) combined with RDI strategies in two different species (mandarin grafted on Carrizo Citrange rootstock and grapefruit grafted on Macrophylla rootstock [*Citrus macrophylla*].

Abbreviations and Nomenclature

C: Control

EC: Electrical Conductivity

ET_0: Reference Evapotranspiration

ET_c: Crop Evapotranspiration

MI: Maturity Index

PT: Peel Thickness

RDI: Regulated Deficit Irrigation

RW: Reclaimed Water

SAR_w: sodium adsorption ratio of water

SSC: Soluble Solid Content

TA: Titratable acidity

Acknowledgement

This work was supported by projects granted to the author's, SIRRIMED (FP7-KBBE-2009-3-245159), CONSOLIDER-INGENIO 2010 (MEC CSD2006-0067), three Spanish Ministry projects with FEDER funds: CICYT (AGL2010-17553; AGL2013-49047-C2-2-R; AGL2016-77282-C3-1-R). The authors are grateful to the Fundación Séneca (19903/GERM/15). Romero-Trigueros, C.

acknowledge the financial support of Fundación Séneca for postdoctoral fellowship (20363/PD/17). Authors declare that there is not conflict of interest.

References

1. Global Water Market. Meeting the world's water and wastewater needs until 2020, *Global Water Intelligence*, 2017; 1, Issue 5.
2. ESAMUR. Entidad de saneamiento y depuración de aguas residuales de la región de Murcia. 2017. http://www.esamur.com accessed March 2017.
3. Martínez-Álvarez, V.; González-Real, M.M.; Baille, A.; Maestre Valero, J.F.; Gallego Elvira, B. Regional assessment of evaporation from agricultural irrigation reservoirs in a semiarid climate. *Agr Water Manag.* **2008**, *95*, 1056–1066.
4. Sonen Capital. Water Investment Primer, Sonen Capital. **2016**. http://www.sonencapital.com/wp2015/wp-content/uploads/2016/06/16WIP.pdf.
5. Nicolás, E.; Alarcón, J.J.; Mounzer, O.; Pedrero, F.; Nortes, P.A.; Alcobendas, R.; Romero-Trigueros, C.; Bayona, J.M.; Maestre-Valero, J.F. Long-term physiological and agronomic responses of mandarin trees to irrigation with saline reclaimed water. *Agr Water Manag.* **2016**, *166*, 1–8.
6. Basheer, L.; Dag, A.; Yermiyahu, U.; Ben-Gal, A.; Zipori, I.; Kerem, Z. Effects of Reclaimed Wastewater Irrigation and Fertigation Level on Olive Oil Composition and Quality. *J Sci Food Agric.* **2019,** DOI:10.1002/jsfa.9911
7. Pereira, B.F.F., Heb, Z.L., Stoffella, P., Melfic, A.J. Reclaimed wastewater: Effects on citrus nutrition. *Agr Water Manage*. **2011**, *98*, 1828-1833.
8. Maas, E.V.; and Grattan, S.R. “Crop yields as affected by salinity”, in *R.W. Skaggs and J. van Schilfgaarde eds Agricultural Drainage*. Agron. Monograph 38. ASA, CSSA, SSSA, Madison, WI. 1999; 55-108.
9. Melgar, J.C.; Mohamed, Y.; Serrano, N.; García-Galavis, P.A.; Navarro, C.; Parra, M.A.; Benlloch, M.; Fernández-Escobar, R. Long term responses of olive trees to salinity. *Agr Water Manag*. **2009**, *96*, 1105–1113.

10. Romero-Trigueros, C.; Nortes, P.A.; Pedrero, F.; Mounzer, O.; Alarcón, J.J.; Bayona, J.M.; Nicolás, E. Assessment of the viability of using saline reclaimed water in grapefruit in medium to long term. *Span J Agr Res.* **2014a**, *124*, 1137–1148.

11. Levy, Y.; and Syvertsen, J.P. Irrigation water quality and salinity effects in citrus trees. *Hortic Rev*. **2004**, *30*, 37–82.

12. Grattan, S.R.; Díaz, F.J.; Pedrero, F.; Vivaldi, G.A. Assessing the suitability of saline wastewaters for irrigation of Citrus spp.: emphasis on boron and specific-ion interactions. *Agr Water Manag*. **2015**, *157*, 48–58.

13. Mounzer, O.; Pedrero-Salcedo, F.; Nortes, P.A.; Bayona, J.M.; Nicolás-Nicolás, E.;Alarcón, J.J. Transient soil salinity under the combined effect of reclaimed water and regulated deficit drip irrigation of mandarin trees. *Agr Water Manag*. **2013**, *120*, 23–29.

14. Pedrero, F.; Maestre, J.F.; Mounzer, O.; Alarcón, J.J.; Nicolás, E. Physiological and agronomic mandarin trees performance under saline reclaimed water combined with regulated deficit irrigation. *Agr Water Manag*. **2014**, *146*, 228-237.

15. Reboll, V.; Cerezo, M.; Roig, A.; Flors, V.; Lapena, L.; García-Agustín, P. Influence of wastewater vs. groundwater on young Citrus trees. *J Sci Food Agr.* **2000**, *80*, 1441-1446. DOI: 10.1002/1097-0010(200008)80:10<1441::AID-JSFA664>3.0.CO;2-S

16. Romero-Trigueros, C.; Nortes, P.A.; Alarcón, J.J. Nicolás, E. Determination of 15N stable isotope natural abundances for assessing the use of saline reclaimed water in grapefruit, *Environ Eng Manage J*. **2014b**, *1310*, 2525-2530.

17. Parsons, L.R.; Wheaton, T.A.; Castle, W.S. High Application Rates of Reclaimed Water Benefit Citrus Tree Growth and Fruit Production. *Hortscience*. **2001**, *36*, 1273–1277. DOI: 10.21273/HORTSCI.36.7.1273

18. Morgan, K.T.; Wheaton, T.A.; Parsons, L.R.; Castle, W.S. Effects of reclaimed municipal waste water on horicultural characteristics, fruit quality and soil and leaf mineral concentration of citrus. *HortScience*. **2008**, *43*, 459-464.

19. Morgan, K.T. “Effects of reclaimed water on citrus growth and productivity”, in *Einschlag, F.S.G Ed., Waste Water – Evaluation and Management*. Intech. **2011**. ISBN: 978-953-307-233-3.

20. Maurer, M. and Davies, F. Use of reclaimed water for irrigation and fertigation of young Redblush grapefruit trees. *Proceedings of the Florida State Horticultural Society*. **1993**, *106*, 22–30.

21. Pedrero, F.; Maestre-Valero, J.F.; Mounzer, O.; Nortes, P.A., Alcobendas, R., Romero-Trigueros, R., Bayona, J.M., Alarcón, J.J., Nicolás, E. Response of young ´Star Ruby` grapefruit trees to regulated deficit irrigation with saline reclaimed water. *Agr Water Manag*. **2015**, *158*, 51–60.

22. Matsumoto, H; Ikoma, Y. Effect of different postharvest temperatures on the accumulation of sugars, organic acids, and amino acids in the juice sacs of satsuma mandarin (*Citrus unshiu* Marc.) fruit. *J. Agric. Food Chem*. **2012**, *60*, 9900–9909. DOI: 10.1021/jf303532s20.

23. Boman, B. Effects of Saline Irrigation Water on Florida Citrus. Final Report. Special Publication SJ2001-SP12. University of Florida, IFAS Indian River Research Education Center, Ft. Pierce, FL, 2001.

24. Levy, Y.; Shalhevet, J.; and Bielorai, H. Effect of irrigation regime and water salinity on grapefruit quality. *J Am Soc Hortic Sci.* **1979***, 104*, 356-359.

25. Navarro, J.M.; Pérez-Pérez, J.G.; Romero, P.; Botía, P. Analysis of the changes in quality in mandarin fruit, produced by deficit irrigation treatments. *Food Chem*. **2010**, *119*, 1591-1596.

26. Navarro, J.M.; Botía, P.; Pérez-Pérez, J.G. Influence of deficit irrigation timing on the fruit quality of grapefruit Citrus paradisi Mac. *Food Chem*. **2015**, *175*, 329-336.

27. Pérez-Pérez, J.G., García-Sánchez, F., Robles, J.M., Botía, P. ‘Star Ruby’ grapefruit and ‘Clemenules’ mandarin trees show different physiological and agronomic responses to irrigation with saline water. *Irrigation Sci*. **2015**, *33*, 191-204.

28. Albertini, M.V.; Carcouet, E.; Paillly, O.; Gambotti, C.; Luro, F.; Berti, L. Changes in Organic Acids and Sugars during Early Stages of Development of Acidic and Acidless Citrus Fruit. *J. Agric. Food Chem*. **2006**, *54*, 8335−8339

29. Ayers, R.S.; and Westcot, D.W. “Water quality for agriculture”, in *FAO Irrigation and Drainage*, Food and Agriculture Organization of the United Nations, Rome, Italy, 1985; 29 Rev. 1, 174.

30. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. “Crop evapotranspiration guidelines for computing crop water requirements”, in *FAO Irrigation and Drainage*, Food and Agriculture Organization of the United Nations, Rome, Italy, 1998; 56, 15–27.

31. Zhou, Y.; He, W.; Zheng, W.; Tan, Q.; Hu, C. Fruit sugar and organic acid were significantly related to fruit Mg of six citrus cultivars. *Food Chem*. **2018**, *259*, 278-285.

32. Bernstein, L.; Brown, J.W.; Hayward, H.E. The influence of rootstock on growth and salt accumulation in stone-fruit trees and almonds. *Proc. Am. Soc. Hort. Sci*. **1956**, *68*, 86–95.

33. Grieve, C.M.; Grattan, S.R.; Maas, E.V. “Plant Salt Tolerance”, in *Agricultural Salinity Assessment and Management* W.W. Wallender and K.K. Tanji, eds. ASCE Manuals and Reports on Engineering Practice. *AM Soc Civ Eng ASCE*. Reston, VA, 2012; No. 71, 2nd edition. 405–459.

34. Conesa, M.R.; García-Salinas, M.D.; de la Rosa, J.M., Fernández-Trujillo, J.P., Domingo, R., Pérez-Pastor., A. Effects of deficit irrigation applied during fruit growth period of late mandarin trees on harvest quality cold storage and subsequent shelf-live. *Sci Hortic.* **2014**, *165*, 344-351.

35. Ballester, C.; Castel, J.; Intrigliolo, D.S.; Castel, J.R. Response of Clementina de Nules citrus trees to summer deficit irrigation. Yield components and fruit composition, *Agr Water Manag*. **2011**, *98*, 1027-1032.

36. García-Sánchez, F.; and Syvertsen, J.P. Salinity reduces growth, gas exchange, chlorophyll and nutrient concentrations in diploid sour orange and related allotetraploid somatic hybrids. *J Hortic Sci Biotechnol*. **2006**, *77*, 379–386.

37. Fellers, P.J.; Carter, R.D.; Dejager, G. Influence of the ratio of degrees Brix to percent acid on consumer acceptance of processed modified grapefruit juice. *J. Food Sci*. **1988**, *53*, 513-515. DOI: 10.1111/j.1365-2621.1988.tb07744.x

38. La Cava, E.L.M.; and Sgroppo, S.C. Evolution during refrigerated storage of bioactive compounds and quality characteristics of grapefruit [*Citrus paradisi Macf.*] juice treated with UV-C light. *LWT-Food Sci. Technol.* **2015**, *632*, 1325-1333.

39. UNECE. Standard Concerning the Marketing and Commercial Quality Control of Citrus Fruit. New York/Geneva, 2010; 12 pp.

Figure 1. (A) Fruit weight (g) and (B) fruit peel thickness (PT, mm) of mandarin trees in 2008 – 2015 period the four treatments (TW-C: transfer water-control, TW-RDI: transfer-regulated deficit irrigation, RW-C: reclaimed water-control, RW-RDI: reclaimed water-regulated deficit irrigation). Each value is the average ± SE of measurements performed in 100 fruits per treatment (25 fruits per block). Within each year, different letters indicate differences among treatment by ANOVA analysis followed of HSD Tukey´s test ($P \leq 0.05$). ns means treatments are not significantly different according to Tukey's HS test ($P < 0.05$).

Figure 2. Maturity index (MI) of mandarin (A) and grapefruit (B) fruit in 2008 – 2015 period the four treatments (TW-C: transfer water-control, TW-RDI: transfer-regulated deficit irrigation, RW-C: reclaimed water-control, RW-RDI: reclaimed water- regulated deficit irrigation). Each value is the average ± SE of measurements performed in 100 fruits per treatment (25 fruits per block). Within each year, different letters indicate differences among treatment by ANOVA analysis followed of HSD Tukey´s test ($P \leq 0.05$). ns means treatments are not significantly different according to Tukey's HS test ($P < 0.05$).

Figure 3. (A) Fruit weight (g) and (B) fruit peel thickness (PT, mm) of grapefruit trees in 2008 – 2015 period the four treatments (TW-C: transfer water-control, TW-RDI: transfer-regulated deficit irrigation, RW-C: reclaimed water-control, RW-RDI: reclaimed water-regulated deficit irrigation). Each value is the average ± SE of measurements performed in 100 fruits per treatment (25 fruits per block). Within each year, different letters indicate differences among treatment by ANOVA analysis followed of HSD Tukey´s test ($P \leq 0.05$). ns means treatments are not significantly different according to Tukey's HS test ($P < 0.05$).

Table 1. Physical and chemical analyses (electrical conductivity, EC; sodium absorption ratio, SAR_w; pH; cations: Ca, Mg, K and Na, and anions: Cl^-, NO_3^-, PO_4^{---} and SO_4^{--} in 2008 – 2015 period for both fresh transfer water (TW) and reclaimed water (RW). Values are averages ± SE for the eight years, with N = 48 for each year's measurements.

Table 2. Soluble solid content (SSC, ºBrix) and titratable acid (TA, %) in mid-term 2008 – 2011 period the four treatments (TW-C: fresh transfer water-control, TW-RDI: fresh transfer-regulated deficit irrigation, RW-C: reclaimed water-control, RW-RDI: reclaimed water- regulated deficit irrigation). Each value is the average ± SE of measurements performed in 100 fruits per treatment (25 fruits per replicate). Within each year, different letters indicate differences among treatment by ANOVA analysis followed of HSD Tukey´s test (P≤0.05).

Table 3. Soluble solid content (SSC, ºBrix) and Tiritable acid (TA, %) in long-term 2012 – 2015 period the four treatments (TW-C: fresh transfer water-control, TW-RDI: fresh transfer-regulated deficit irrigation, RW-C: reclaimed water-control, RW-RDI: reclaimed water- regulated deficit irrigation). Each value is the average ± SE of measurements performed in 100 fruits per treatment (25 fruits per replicate). Within each year, different letters indicate differences among treatment by ANOVA analysis followed of HSD Tukey´s test (P≤0.05).

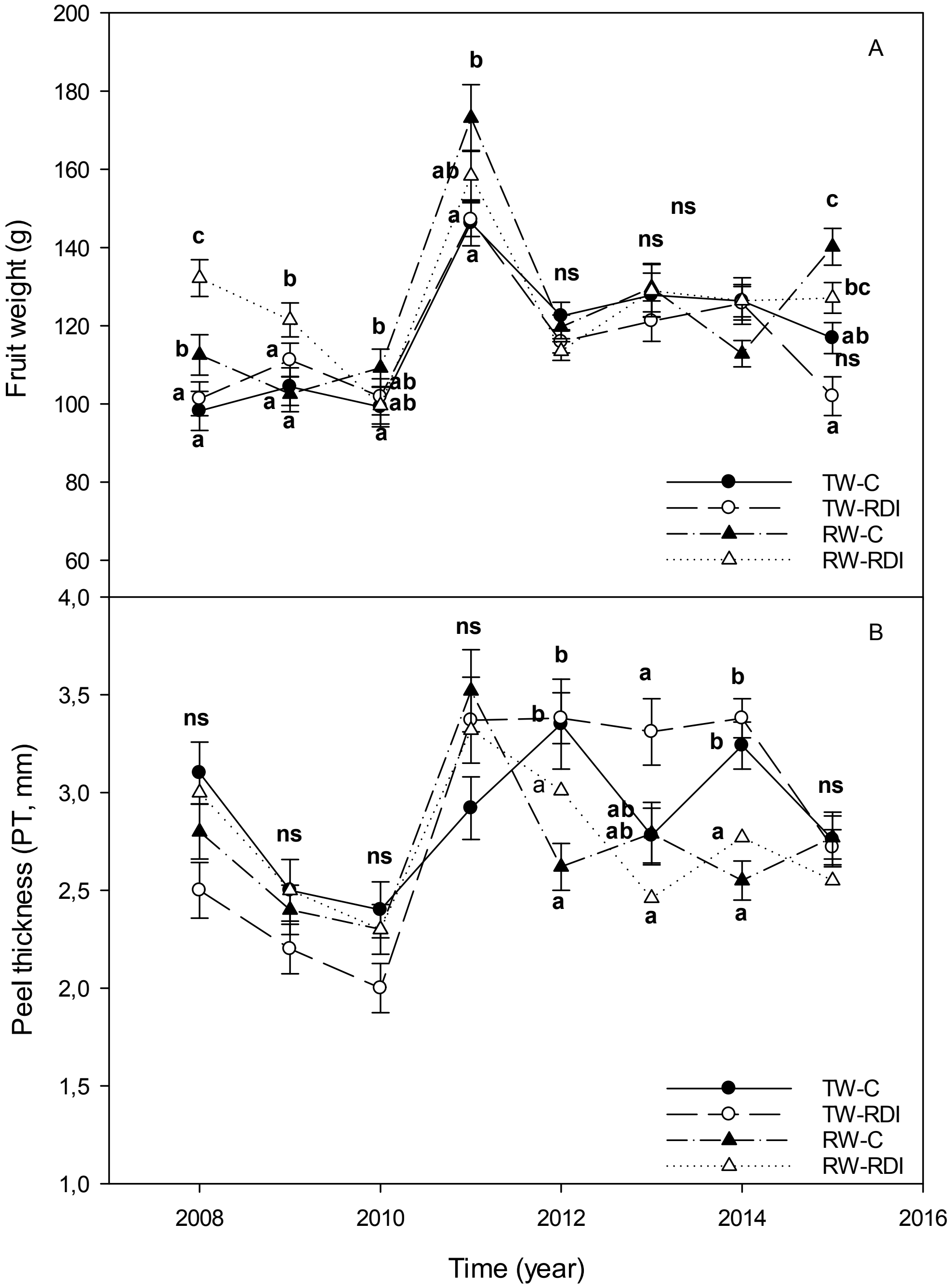

Figure 1. (A) Fruit weight (g) and (B) fruit peel thickness (PT, mm) of mandarin trees in 2008 – 2015 period the four treatments (TW-C: transfer water-control, TW-RDI: transfer-regulated deficit irrigation, RW-C: reclaimed water-control, RW-RDI: reclaimed water-regulated deficit irrigation). Each value is the average ± SE of measurements performed in 100 fruits per treatment (25 fruits per block). Within each year, different letters indicate differences among treatment by ANOVA analysis followed of HSD Tukey´s test (P≤0.05). ns means treatments are not significantly different according to Tukey's HS test (P < 0.05).

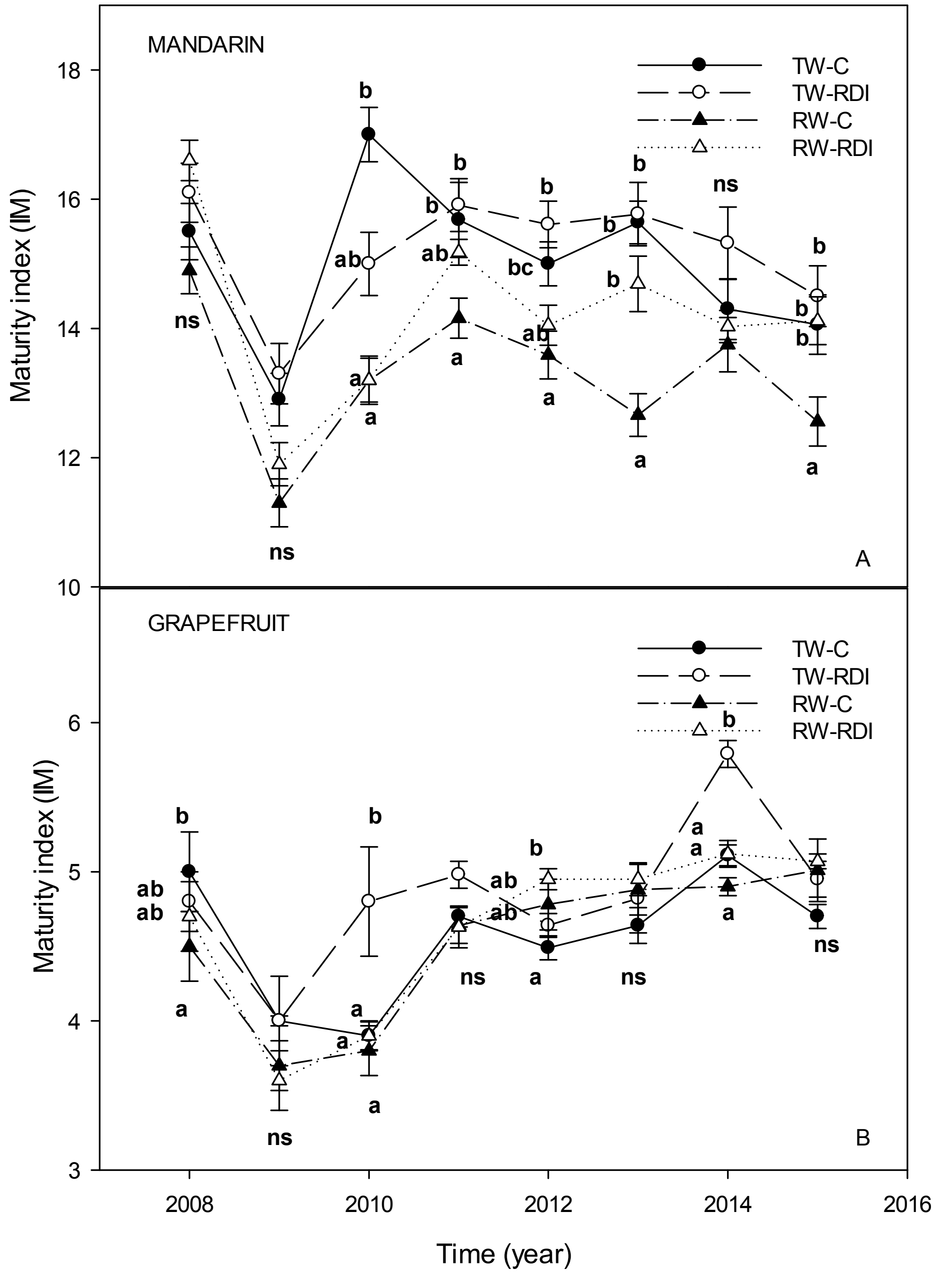

Figure 2. Maturity index (MI) of mandarin (A) and grapefruit (B) fruit in 2008 – 2015 period the four treatments (TW-C: transfer water-control, TW-RDI: transfer-regulated deficit irrigation, RW-C: reclaimed water-control, RW-RDI: reclaimed water- regulated deficit irrigation). Each value is the average ± SE of measurements performed in 100 fruits per treatment (25 fruits per block). Within each year, different letters indicate differences among treatment by ANOVA analysis followed of HSD Tukey´s test (P≤0.05). ns means treatments are not significantly different according to Tukey's HS test (P < 0.05).

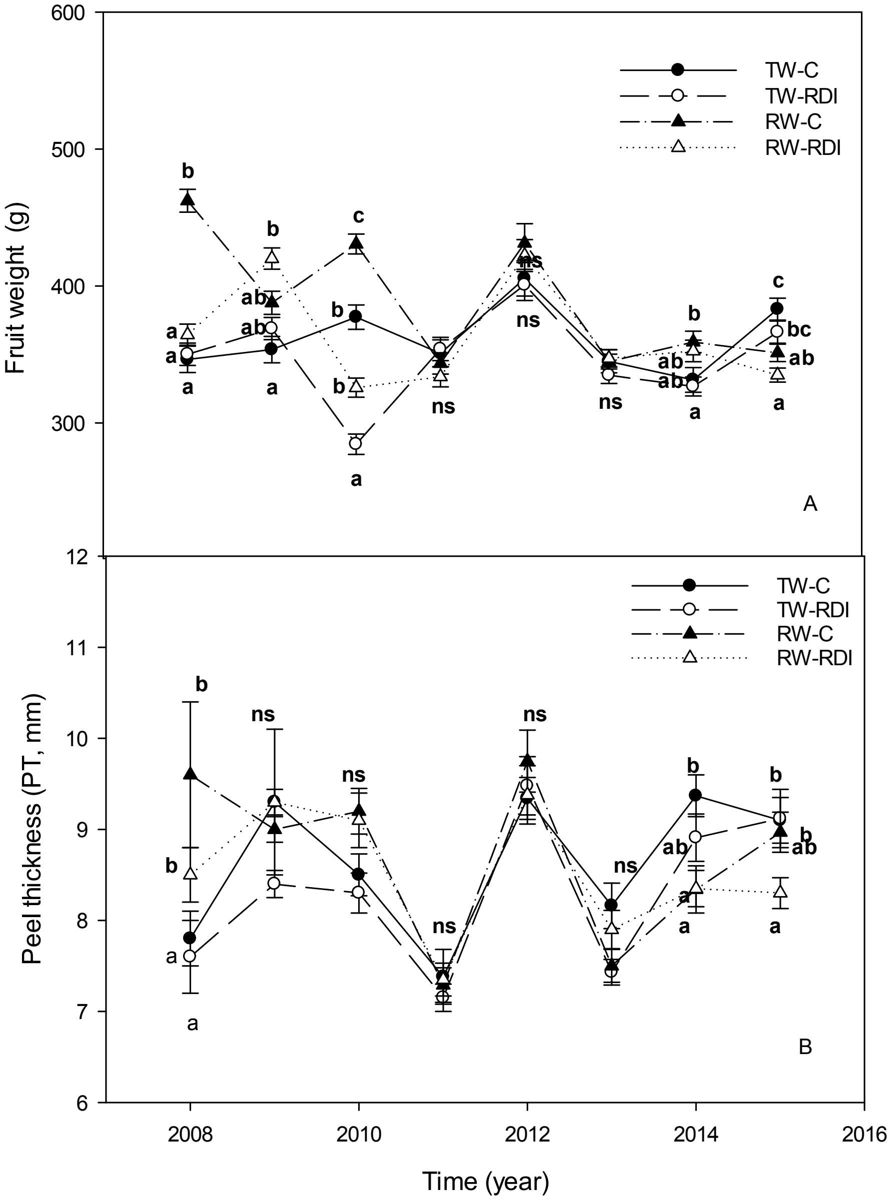

Figure 3. (A) Fruit weight (g) and (B) fruit peel thickness (PT, mm) of grapefruit trees in 2008 – 2015 period the four treatments (TW-C: transfer water-control, TW-RDI: transfer-regulated deficit irrigation, RW-C: reclaimed water-control, RW-RDI: reclaimed water-regulated deficit irrigation). Each value is the average ± SE of measurements performed in 100 fruits per treatment (25 fruits per block). Within each year, different letters indicate differences among treatment by ANOVA analysis followed of HSD Tukey´s test (P≤0.05). ns means treatments are not significantly different according to Tukey's HS test (P < 0.05).

Table 1. Physical and chemical analyses (electrical conductivity, sodium absorption ratio, pH, cations: Ca, Mg, K and Na, and anions: Cl^-, NO_3^-, PO_4^{---} and SO_4^{--}) in the 2008 – 2015 period for both fresh transfer water (TW) and reclaimed water (RW). Values are averages ± SE for the eight years, with N = 48 for each year's measurements.

	Units	2008 - 2015	
		TW	RW
EC_w	dS m^{-1}	1.00±0.12	3.51±0.31
SAR	(meq $L^{-1})^{0.5}$	1.28±0.49	7.78±1.96
pH		8.18±1.00	7.88±0.31
Ca	meq L^{-1}	4.28±0.58	6.69±1.12
Mg	meq L^{-1}	3.23±0.53	7.55±1.77
K	mg L^{-1}	5.09±2.70	42.69±6.55
Na	meq L^{-1}	2.70±0.58	20.69±3.55
B	mg L^{-1}	0.10±0.02	0.68±0.09
Cl^-	meq L^{-1}	3.10±0.80	18.64±4.20
NO_3^-	mg L^{-1}	9.33±4.74	21.17±12.44
PO_4^{---}	mg L^{-1}	0.53±0.10	2.00±1.31
SO_4^{--}	meq L^{-1}	6.89±1.37	16.23±5.23

EC_w: electrical conductivity; SAR_w: sodium absorption ratio;

Table 2. Soluble solid content (SSC, ºBrix) and Tiritable acid (TA, %) in mid-term 2008 – 2011 period the four treatments (TW-C: fresh transfer water-control, TW-RDI: fresh transfer-regulated deficit irrigation, RW-C: reclaimed water-control, RW-RDI: reclaimed water- regulated deficit irrigation). Each value is the average ± SE of measurements performed in 100 fruits per treatment (25 fruits per replicate). Within each year, different letters indicate differences among treatment by ANOVA analysis followed of HSD Tukey´s test (P≤0.05).

		MANDARIN		GRAPEFRUIT	
Year	**Treatment**	**SSC (ºBrix)**	**TA (%)**	**SSC (ºBrix)**	**TA (%)**
2008	**TW-C**	9.9±0.1c	0.80±0.04a	12.4±0.1a	1.98±0.13a
	TW-RDI	8.6±0.1b	0.80±0.04a	12.9±0.1a	1.79±0.10a
	RW- C	7.9±0.0a	0.90±0.04a	13.4±0.0a	1.76±0.09a
	RW-RDI	8.3±0.1b	0.80±0.03a	13.3±0.1a	1.77±0.11a
2009	**TW- C**	8.1±0.9a	0.90±0.05a	11.6±0.9a	2.03±0.38a
	TW-RDI	9.6±1.0a	0.90±0.05a	12.0±1.0a	2.40±0.27a
	RW- C	9.4±1.6a	1.00±0.05a	11.3±1.6a	2.54±0.55a
	RW-RDI	9.2±1.1a	1.00±0.05a	11.9±1.1a	2.56±0.45a
2010	**TW- C**	9.8±0.6ab	0.80±0.04a	13.6±0.6a	2.51±0.21a
	TW-RDI	10.6±1.3b	0.90±0.05a	13.5±1.3a	2.21±0.44a
	RW- C	9.1±0.5a	0.99±0.05a	13.1±0.5a	2.39±0.24a
	RW-RDI	10.0±1b	1.00±0.04a	13.2±1.0a	2.56±0.32a
2011	**TW-C**	8.98±0.10a	0.82±0.03a	12.66±0.23ab	1.92±0.03a
	TW-RDI	8.81±0.12a	0.82±0.02a	12.91±0.21ab	1.78±0.04a
	RW- C	9.79±0.12b	0.87±0.02a	12.35±0.25a	2.12±0.04b
	RW-RDI	9.74±0.09b	0.87±0.02a	13.22±0.18b	2.13±0.06b
Mid-term average (2008-2011)	**TW-C**	9.20±0.43a	0.83±0.04a	12.57±0.46a	2.11±0.19a
	TW-RDI	9.40±0.63a	0.86±0.04a	12.83±0.65a	2.05±0.21a
	RW- C	9.05±0.56a	0.94±0.04a	12.54±0.59a	2.20±0.23a
	RW-RDI	9.31±0.57a	0.92±0.04a	12.91±0.60a	2.26±0.24a

Table 3. Soluble solid content (SSC, ºBrix) and Tiritable acid (TA, %) in long-term 2012 – 2015 period the four treatments (TW-C: fresh transfer water-control, TW-RDI: fresh transfer-regulated deficit irrigation, RW-C: reclaimed water-control, RW-RDI: reclaimed water- regulated deficit irrigation). Each value is the average ± SE of measurements performed in 100 fruits per treatment (25 fruits per replicate). Within each year, different letters indicate differences among treatment by ANOVA analysis followed of HSD Tukey´s test (P≤0.05).

		MANDARIN		GRAPEFRUIT	
Year	Treatment	SSC (ºBrix)	TA (%)	SSC (ºBrix)	TA (%)
2012	TW- C	8.85±0.24a	0.83±0.02a	12.38±0.27bc	2.01±0.05a
	TW-RDI	9.16±0.19ab	0.83±0.01a	12.90±0.16c	2.04±0.08a
	RW- C	9.56±0.09b	0.85±0.03a	11.48±0.21a	2.11±0.12a
	RW-RDI	9.12±0.12ab	0.86±0.02a	12.00±0.16ab	1.86±0.02a
2013	TW- C	8.33±0.38a	0.76±0.01a	11.87±0.25a	1.83±0.05a
	TW-RDI	9.38±0.39ab	0.88±0.03b	13.61±0.29b	1.99±0.15a
	RW- C	9.68±0.22b	0.97±0.02c	12.16±0.36a	1.99±0.03a
	RW-RDI	9.24±0.31ab	0.87±0.02b	12.72±0.24ab	1.87±0.06a
2014	TW- C	8.39±0.10a	0.79±0.03a	11.27±0.29a	1.72±0.02a
	TW-RDI	9.41±0.14b	0.79±0.02a	12.06±0.28ab	1.71±0.04a
	RW- C	8.42±0.18a	0.84±0.01ab	11.44±0.28ab	1.80±0.04a
	RW-RDI	8.68±0.27a	0.89±0.02b	12.39±0.20b	1.78±0.06a
2015	TW- C	8.78±0.05a	0.70±0.02a	9.79±0.31a	1.87±0.02a
	TW-RDI	9.82±0.22b	0.73±0.01ab	10.58±0.36bc	1.99±0.06a
	RW- C	9.73±0.12b	0.80±0.03b	10.05±0.14ab	1.96±0.06a
	RW-RDI	9.96±0.12b	0.78±0.03ab	10.95±0.24c	1.96±0.03a
Average 2012-2015 Long-term	TW-C	8.59±0.19a	0.77±0.02a	11.33±0.28a	1.86±0.04a
	TW-RDI	9.44±0.24b	0.81±0.02ab	12.29±0.27b	1.93±0.08a
	RW- C	9.35±0.15b	0.87±0.02b	11.28±0.25a	1.97±0.06a
	RW-RDI	9.25±0.21ab	0.85±0.02b	12.02±0.21b	1.87±0.04a