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Use of reclaimed wastewater on fruit quality of nectarine in Southern Italy

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ABSTRACT

The feasability of using reclaimed water (RW) to irrigate nectarines in Apulia, to reduce sea-water intrusion, has been studied in an orchard for 3-years. While the primary water quality parameters were significantly higher in RW than in fresh water (FW), concentrations were below the phytotoxic threshold that would cause significant yield losses under good management practices. In general, fruit quality parameters of nectarines, total phenolics and antioxidant compounds were higher in fruits irrigated with RW than FW, because of higher nutrients and salinity in the RW treatment. Lower firmness values were observed in RW-treated fruits implying early ripening. Overall, no yield differences were found between FW and RW-treated trees during the three year study. However, the RW treatment significanly reduced the number of fruits but this reduction was compensated by a larger individual fruit weight. While this 3yr-study has demonstrated that reclaimed water is a feasable alternative to freshwater in areas in southern Italy, further long-term studies are still needed to show the beneficial effects of RW on nectarine fruit yield and quality.

1. Introduction

Apulia is a region in south-eastern Italy that extends over 19 thousand km^2, including about 800 km of coastlines and 4,500,000 inhabitants. Among all Italian regions, Apulia has the smallest amount of available water (136 m^3 capita per year^{-1}) and the lowest average annual rainfall (i.e. about 660 mm^{-1}) (Lopez et al., 2010). Nevertheless, its economy is ranked as one of the best in southern Italy, supported largely by two water-demanding activities, tourism and agriculture. Most of the Apulian land is used for agricultural purposes but only about a quarter of the cultivated area is irrigated (i.e. 3653 km^2) (Disciglio et al., 2014). The annual Apulian water consumption is estimated to be around 1500 hm^3 of which 55% comes from regional resources and 45% is imported from bordering regions (Campania, Molise, Basilicata) by the Apulian Aqueduct (i.e. the largest in Europe with its 19,635 km of pipe-distribution network).

Some studies (Alcalde and Gawlik, 2014; Regione, 2012; Raso, 2013; Levine and Asano, 2004) show that the improvement of urban wastewater treatment, as consequence of population growth and tourism, would increase the regional annual wáter availability for irrigation by 60 million m^3, about 10% of the overall irrigation water demand (Arborea et al., 2017). Such a supplemental source of wáter would help satisfy agriculture needs which is a high demand in this semi-arid region.

While an attractive option, use of reclaimed water for irrigation has important issues that must be addressed. For example salinity and over-application of nutrients are problems associated with reclaimed-water irrigation in arid and semi-arid environments. Soil salinization is a major threat in fruit trees since they are among the most salt-sensitive horticultural crops (FAO, 1985). Approximately 6% of world cultivated land has salinity problems where NaCl is usually the most abundant and soluble salt (Hasegawa et al., 2000; Munns and Tester, 2008)). In Apulia region, it has been estimated that regional farmers have drilled more than 200,000 wells, whose extensive exploitation of groundwater resources is causing the progressive salinization and depletion of relevant portions of the regional aquifers reducing the quality and availability of water for agriculture. This phenomenon is particularly relevant along the coastline where a sharp increase in salinity of the groundwater has been recorded, with peaks as high as 2 dS m^{-1} (Maggiore et al., 2001).

Nectarine production has a growing economic importance worldwide and in southern Italy, the Apulia Region is the leading producer. For nectarine, both fruit quantity and quality are important as other factors like early-ripening, deficit irrigation and yield variability;

Abbreviations: RW, reclaimed water; FW, fresh water; SSC, soluble solid content; TA, titratable acidity; F, firmness; MI, maturity index; CO, colour; CH, chinoni; TP, total phenolic; AC, antioxidant capacity; RE, respiration rate; TS, total sugar content

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Zarini, 2014). In regards to variability, several studies focusing on precision irrigation on peach fruit quality and quantity have been done. For example, deficit irrigation strategies (Elnesr et al., 2016; Mirás-Avalos et al., 2016), have shown that fruit quality, particulary the soluble solid content, has been improved (Pliakoni and Nanos, 2010). But such a quality improvement can lead to a yield reduction, at least to some extent (Abrisqueta et al., 2010; Rufat et al., 2010). Deficit irrigation strategies can also cause fruit peel stress, reduction on vitamin C and carotenoids, and an increase in the phenolic content, mainly anthocyanins, and procyanidins (Buendía et al., 2008). In general, stone fruit crops tend to manifest a moderate to high sensitivity to salinity. Several interesting studies have been conducted in *Prunus* but with artificial salty irrigation water (Gainza et al., 2015; Massai et al., 2004), which simulates increased salt content in reclaimed water. On irrigation water quality effects on peach fruit quality, especially reclaimed water, experiments are limited or too old (Basiouny, 1984; Lurie et al., 1996), or focus on fruit safety (Vivaldi et al., 2013)or short term effects on fruit quality (Vivaldi et al., 2017). For that reason the aim of this work was to study the effects of reclaimed water on the fruit quality and yield in drip-irrigated nectarine trees over a three-year duration.

2. Materials and methods

2.1. Experimental site

A three year study (2012–2014) was carried out in a comercial nectarine grove (*Prunus persica* L. Batsch.) cv Big Top grafted on GF-677. The grove was planted in 2008 and is located in Trinitapoli (Apulia Region, Southern Italy, 41°22′.92″N; 16°03′16.27″E; Altitude 1m). The climate of the experimental area is classified as semiarid, like the 75.3% of the Region (Kapur et al., 2010). The planting density was 400 trees ha^{-1} with 5 m spacing between rows and 5 m between trees; the trees were vase-shaped trained. The soil was sandy loam and was classified as Vertisol-Gleysols (FAO) The main physical and chemical characteristics of the soil are reported in (Vivaldi et al., 2013).

A total of 80 trees were used in this study. The experimental design was a randomized complete design with 4 blocks and four experimental plots per block (one per each irrigation water source). The standard plot was made up of 5 trees, located in 4 adjacent rows. The three central trees of the middle row were used for measurements, and the other 2 trees were guard trees.

Fertilizers were applied taking into account nectarine nutrient requirements (102, 27, 0 kg ha^{-1} of N_2, P_2O_5, K_2O respectively). All other agricultural practices (pruning, weed and pest control) were performed following the regional production best good practices.

The climatic conditions were almost similar during the experimental period (2012–2014), with an average temperature of 17 °C, 67% relative humidity and rainfall around 500 mm. Rainfall was more variable during the irrigation period (May-September), from 90.4 mm during 2012 to nearly double the amount (i.e. 176.2 mm) in 2014. For that reason, the amount of irrigation water applied in 2013 and 2014 were higher respect to 2012 (3100, 4024 and 3715 m^3 ha^{-1}, respectively).

2.2. Irrigation water sources, management and quality

Two water sources were used in the experiment. The first water source was a reclaimed water from a tertiary-treated wastewater (RW) produced by membrane filtration from a wastewater treatment plant located near the experimental site, more technical details are described in (Vivaldi et al., 2013). This treatment was compared with fresh water source (FW) from the Marana Capacciotti dam which served as the control.

Trees were irrigated by drip irrigation with drip lines suspended along rows on the Trees 1.70 m above the soil surface. Two self-compensating drippers delivered water at 12 L h^{-1} to each tree. The distance of the drippers from the trunk was 1 m. The irrigation volume has

Table 1
Chemical parameters for both fresh water (FW) and reclaimed water (RW). Each data represents the mean of 27 values ± the standard deviation measured on water samples collected during 2012, 2013 and 2014.

Parameter	FW	RW	*t-test*
pH	7.73 ± 0.20	7.51 ± 0.21	ns
EC ($dS\,m^{-1}$)	0.63 ± 0.03	1.39 ± 0.10	*
SAR	1.51 ± 0.24	2.99 ± 0.39	*
F^- ($mg\,l^{-1}$)	0.99 ± 0.52	1.61 ± 1.12	*
Cl^- ($mg\,l^{-1}$)	37.08 ± 7.16	161.46 ± 23.18	*
NO_3^- ($mg\,l^{-1}$)	2.80 ± 1.97	1.32 ± 1.16	*
PO_4^{3-} ($mg\,l^{-1}$)	0.54 ± 0.83	14.04 ± 8.56	*
SO_4^{2}- ($mg\,l^{-1}$)	59.03 ± 13.30	99.35 ± 18.64	*
NH_4^+ ($mg\ ^{-1}l$)	0.89 ± 0.99	40.87 ± 12.79	*
Na^+ ($meq\,l^{-1}$)	2.02 ± 0.37	4.84 ± 0.44	*
K^+ ($mg\,l^{-1}$)	6.12 ± 3.29	27.66 ± 5.27	*
Ca^{2+} ($meq\,l^{-1}$)	2.89 ± 0.64	4.01 ± 0.58	*
Mg^{2+} ($meq\,l^{-1}$)	0.75 ± 0.37	1.36 ± 0.45	*

Mean content (n = 27) * Statistically significant at $P < 0.05$ level of significance.

been calculated by the water balance method, with restitution of 100% crop evapotranspiration (ETc) lost in each irrigation interval. ETc was calculated using Eq. (1) recommended by FAO:

$$ETc = Kr\ Kc\ ET_0 \quad (1)$$

were Kr is reduction coefficient (Kr = 0.75), Kc (0.50 Kc_{ini}, 1.15 Kc_{mid}, 0.85 Kc_{end}) is crop coefficient, ET_0 is reference evapotranspiration. ET_0 was calculated by Penman–Monteith equation and directly provided by ASSOCODIPUGLIA (www.agrometeopuglia.it).

Nine water samples from each irrigation water source were collected yearly during the irrigation period (May-September) between 2012 and 2014 in order to characterize irrigation water quality throughout the irrigation season. The water analysis were done as reported in (Vivaldi et al., 2017).

RW had almost triple the salinity, with electrical conductivity (EC) values close to 1.5 dS m^{-1} vs 0.5 dS m^{-1} for that of FW. The SAR of the RW (3.0) was double that of the FW (Table 1). The higher salinity level observed in RW was mainly due to the high concentration of Cl (161.4 mg L^{-1}) and Na (4.8 meq L^{-1}) (Table 1), although Ca, Mg and SO_4 were also more concentrated in RW. RW also had higher concentrations of nutrients than FW, specially macronutrients (NO_3, PO_4 and K) that were 2, 28 and 5 times higher in RW, respectively.

2.3. Fruit measurements

2.3.1. Fruits yield and quality

Fruit yield and number of fruits per tree were measured from 12 trees in each treatment from 2012 to 2014. As peaches do not mature all at once, were established three commercial harvests periods, during the Julian days: 190, 195 and 200 in 2012, 183,191 and 199 in 2013, and 182,190 and 198 in 2014, based on firmness and the marketing of the grower.

Samples (180 fruits for each treatment) were randomly collected by hand in the middle part of the tree. Fresh weight (g), equatorial diameters (mm), flesh firmness (F; kg cm^{-2}), soluble solids content (SSC; °Brix), titratable acidity (TA; mg L^{-1}), pH, and maturity index (MI) were determined in the laboratory one day after harvest. Flesh firmness was measured with an 8-mm tip penetrometer (Effegi, Milan, Italy) on two peeled surfaces on opposite sides of the equatorial region of the fruit. SSC and TA were measured in juice pressed from the whole fruit: SSC was determined with a hand refractometer (Atago, Tokyo, Japan); TA was determined by titrating 10 mL of juice with 0.1 N NaOH to pH 8.1 and calculating the result as malic acid (mg L^{-1}). The pH values were measured using a pH meter (Crison 507; Crison Instruments, S.A., Barcelona, Spain). MI, calculated as the SSC/TA ratio, was used as an indication of fruit maturity at field harvest.