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Reuse of treated municipal wastewater for globe artichoke irrigation: Assessment of effects on morpho-quantitative parameters and microbial safety of yield

Giuseppe Gatta[a,*], Angela Libutti[a], Luciano Beneduce[a], Anna Gagliardi[a], Grazia Disciglio[a], Antonio Lonigro[b], Emanuele Tarantino[a]

[a] Department of Agricultural, Food and Environmental Sciences, University of Foggia, Foggia, Italy
[b] Department of Agricultural and Environmental Science, University of Bari, Italy

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ABSTRACT

This study was performed over two growing seasons to evaluate the effects of three irrigation sources on the morpho-productive and microbiological parameters of globe artichoke yields: secondary wastewater (SWW), tertiary wastewater (TWW), and fresh water (FW, control).

Escherichia coli, faecal enterococci and *Salmonella* spp. were monitored in the irrigation waters, the artichoke plants and heads, and the root-zone soil. Bacteriological analysis for total heterotrophic counts were determined for plants, fruit and soil. The irrigation waters were sampled, throughout the irrigation period of the crop, to characterise their physico-chemical properties. The chemical parameters of the SWW (i.e., TSS, BOD_5 and COD) were significantly higher compared with those of the FW and TWW. The SWW and TWW significantly affected total marketable heads as number and weight per hectare, with higher yields than for the FW. Total marketable heads (as main, secondary, processing heads) were significantly higher in terms of weight per hectare for the SWW and TWW than for the FW (25%, 16% increases, respectively), as was the main head production for marketable weight (57%, 33% increases, respectively). The microbial qualities of the SWW and TWW were significantly different, with the SWW characterised by higher levels of *E. coli* and faecal coliforms, while frequently positive for *Salmonella* spp. Nevertheless, the microbial safety of the artichoke yield was not affected. The reduction in all of the faecal indicators from water to soil and from soil to plant can be explained by the irrigation system, which avoids direct contact of water with plant and aerosol dispersion; by the relatively rapid die-off of faecal bacteria in the soil; and a possible barrier effect of the rhizosphere environment. These data show that if municipal wastewaters are adequately treated, they can be used for irrigation. Thus, they represent a valid alternative to conventional water resources for irrigation of artichoke crops.

1. Introduction

Globe artichoke [*Cynara cardunculus* var. *scolymus* (L.) Fiori] is an important crop in the Mediterranean Basin (Pandino et al., 2011; Mauro et al., 2011; Rottenberg, 2015). It is cultivated for its edible part, known as the ‘capitula’ or ‘head’. The annual world production of artichoke heads is approximately 1700 kt, distributed across many continents, including in particular, southern Europe (i.e., Italy, Spain, France, Greece), the Middle East (i.e., Turkey, Syria, Israel), northern Africa (i.e., Egypt, Morocco, Algeria, Tunisia), and in the last few years, China as well (FAO, 2013). Italy is the highest producer in the world, at approximately 477 kt per year, with artichoke cultivation mainly occurring in southern Italy (i.e., Sicily, Sardinia, Apulia region). In this area, the artichoke represents one of the most important irrigated herbaceous crops, with a cultivation area measuring approximately 17,000 ha and accounting for over 35% of national production (Boari et al., 2000).

Under the conditions of the Mediterranean climate, artichoke productivity is strongly affected by the amount of irrigation water used (Saleh et al., 2012). The Mediterranean area is characterised by hot summers with moderate cool winters and low annual rainfall. Despite intensive irrigation, rural communities are seriously affected by frequent droughts and by increased restrictive regulations on agricultural water use. In countries that suffer from

* Corresponding author.
E-mail address: giuseppe.gatta@unifg.it (G. Gatta).

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drought, treated wastewaters can be used to reduce the gap between supply and demand of irrigation water. Thus, such treated wastewaters might represent an advantageous alternative for mitigation of the ever-increasing scarcity of irrigation water (Christou et al., 2014).

The use of reclaimed wastewater for crop irrigation is also considered a technical solution for minimising soil degradation and restoring the nutrient contents of soil (Plauborg et al., 2010; Khurana and Singh, 2012). The economic and environmental benefits of wastewater reuse in agriculture have been demonstrated through case studies around the world, and many researchers have recognized these benefits (MuLevine and Asano, 2004; Hamilton et al., 2007; Kiziloglu et al., 2008). The application of treated wastewater to croplands is an attractive option for disposal because it can improve the physical properties and the fertility of the soil (Abusam and Al-Anzi, 2011; Christou et al., 2014; Almuktar et al., 2015) in terms of the content of nitrogen, phosphorus, organic matter, and other trace elements, thus providing a good source of nutrients for the growth, yield and quality of crops (Benitez et al., 2001; Khurana and Singh, 2012; Almuktar and Scholz, 2016). Improvements in the physico-chemical characteristics of soil through the use of wastewaters for irrigation have often positively influenced crop production, and in some cases, these improvements can benefit the quality parameters of crop yields (Kiziloglu et al., 2007). However, reclaimed wastewaters can contain undesirable pathogens that can have negative environmental and health impacts (Muchuweti et al., 2006; Bernstein, 2011; Forslund et al., 2012). Several studies have been carried out on crops in Mediterranean environments to evaluate the effects of the reuse of treated wastewaters (i.e., municipal, agro-industrial wastewaters) for the irrigation of plants with edible products and the microbiological properties of the yield (Aiello et al., 2007; Sacks and Bernstein, 2011; Cirelli et al., 2012; Lonigro et al., 2015; Almuktar and Scholz, 2015; Al-Isawi et al., 2016; Orlofsky et al., 2016), although there have been very few studies regarding the globe artichoke. In a multi-year study carried out in southern Italy on a rotation of herbaceous vegetable crops (i.e., processing tomato, fennel, lettuce) irrigated with two types of treated municipal wastewaters, no significant differences in crop production or accumulation of heavy metals in soil and plants were observed (Lonigro et al., 2007). The results of another study on tomato and potato crops showed that reclaimed wastewater irrigation use had no significant effect on the commercial production and microbiological pollution of the edible parts of vegetables (Brar et al., 2000; Gatta et al., 2015).

International legislative approaches vary greatly in terms of the establishment of the most appropriate levels of contamination of wastewaters used for agricultural irrigation. The approach of the World Health Organisation Guidelines (Blumenthal et al., 2000) is relatively flexible, and it is intended to support the establishment of national standards, whereby each country should review its needs with the development of their specific regulatory framework. However, many countries have chosen to make their local laws with threshold values more restrictive.

With regard to microbiological contamination levels, the Italian guidelines (Legislative Decree no. 185/2003 of the Ministry for the Environment) have defined significantly lower threshold values than those included in international guidelines, such as 10 CFU 100 ml^{-1} for *E. coli* in 80% of samples. Such threshold values can be considered highly restrictive because effective effluent management strategies, including those targeting wastewater treatment levels, crops grown, cultivation techniques (e.g., mulching, irrigation method) and pathogen die-off between the final irrigation and crop consumption, can greatly reduce the contamination of irrigated vegetables and soil (Pereira et al., 2002; World Health Organisation, 2006; Aiello et al., 2007). These factors can thus make the use of agronomic treated wastewaters highly 'site-specific'.

The aim of the present study was to determine the effects of two different treated municipal wastewaters on globe artichoke crop performance, as compared to freshwater (FW) use: secondary treated wastewater (SWW) and tertiary treated wastewater (TWW). The goals of this study were thus to (i) determine the morpho-quantitative parameters of artichoke heads in response to these different irrigation water treatments; and (ii) determine the impact of these municipal wastewaters on the microbiological parameters of the soil, plants and microbial safety of marketable yield.

2. Materials and methods

2.1. Site description and climate conditions

This study was carried out over two growing seasons, as GS_1 from 2012 to 2013 and GS_2 from 2013 to 2014, at Trinitapoli (Apulia region, southern Italy; 41°21′ N, 16°03′ E; altitude, 10 m a.s.l.). The artichoke crop [*Cynara cardunculus* (L.), subsp. *scólymus Hayek*] used was cv. 'Violetto of Provenza', grown in a field that had previously been cultivated with durum wheat. The experimental trial was carried out in a loam soil (United States Department of Agriculture classification) with a field capacity (−0.03 MPa) of 30.7% dry weight (dw), a wilting point (−1.5 MPa) of 15.2% dw, and a bulk density of 1.45 Mg m^{-3}. The main characteristics of the soil layer of the experimental site (for the 0-0.6 m layer) were as follows: sand, 45.3%; silt 30.0%; clay 24.7%; organic matter 1.2%; available P, 114.0 mg kg^{-1}; total K, 1.27 g kg^{-1}; total N (Kjeldahl) 0.91‰, mineral NO_3-N, 7.9 mg kg^{-1}; mineral NH_4-N, 3.8 mg kg^{-1}; pH 8.1; electrical conductivity, 1.1 dS m^{-1}.

The experimental site was characterised by a Mediterranean climate, with a long-term (1977–2011) mean annual rainfall of 560 mm, which was mainly distributed from October to April (Campi et al., 2016). During the experimental period, the daily climatic parameters of rainfall, temperature, relative air humidity and wind speed were recorded. These parameters were measured by a weather station near to the experimental area that belonged to the Agro-Meteorological Service of the "*Consorzio di Bonifica della Capitanata*" (www.consorzio.fg.it).

Fig. S_1 (see Supplementary materials) illustrates the main climatic conditions over the two growing seasons considered. The maximum and minimum air temperatures were 40.1 °C and −2.5 °C, respectively, in GS_1 and 39.4 °C and −1.0 °C, respectively, in GS_2. In the two growing seasons, the cumulative rainfall amounts were 597 and 545 mm for GS_1 and GS_2, respectively. According to the Mediterranean climate, the rainfall across both the two crop cycles was concentrated in the middle months of the year (i.e., October-March), as about 390 mm for GS_1 and about 300 mm for GS_2.

2.2. Irrigation treatments

Three irrigation sources (treatments) were compared in this study: SWW and TWW that originated from a public municipal plant and FW as the control. For the SWW, the effluent, obtained from a secondary wastewater treatment plant, was passed through primary clarifiers. It then underwent an activated-sludge process with partial aerobic stabilisation of the sludge, and finally, treatments for the chemical precipitation of phosphorus and for denitrification and chlorination were applied. The TWW was obtained from a membrane ultra-filtration public plant located near to the experimental site. The TWW and SWW were stored in two