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Agro-industrial wastewater reuse for irrigation of a vegetable crop succession under Mediterranean conditions

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ABSTRACT

In many countries of the Mediterranean region, characterized by frequent drought periods, agricultural production often occurs under water deficiency or conditions that cause the depletion of the existing water resources. In these areas, the reuse of reclaimed wastewater for crop irrigation could contribute to mitigate/decrease water shortage, support the agriculture sector and protect groundwater resources. In 1.5-year field experiments in Southern Italy (Apulia Region), the effects of irrigation with treated agro-industrial wastewater on soil properties, crops yield and qualitative traits of crop products, including their microbiological safety, were assessed. Groundwater (GW), secondary treated wastewater (SW) and tertiary treated wastewater (TW) from an innovative "on-demand" UV disinfection system were used to irrigate tomato and broccoli, cultivated in succession. The three irrigation water sources and the corresponding irrigated soils, plants and crop products were analyzed for the main physico-chemical characteristics, quali-quantitative parameters and fecal indicators. SW and TW showed higher values of the main physico-chemical parameters than GW. SW irrigated soil resulted in a significant increase of NH_4-N, Na^+, SAR, EC (below the threshold value beyond which a soil is defined as saline) during the first tomato crop cycle, and of pH during the broccoli growing season. Irrigation with treated wastewater did not significantly affect the marketable yield nor the qualitative traits of tomato and broccoli crops, except for the Na^+ and NO_3^- content (below the threshold levels defined by the European guidelines for vegetables). High levels of *E. coli* (above the Italian limit for reuse), *Fecal coliforms* and *Fecal enterococci* (up to 10^4 CFU $100\,ml^{-1}$) were observed in the SW and, when chlorination was not done, in the TW. Nevertheless, *E. coli* was not isolated from any sample of soil, plant and crop product, probably due to its rapid die-off. Moreover, low concentrations of *Fecal coliforms* and *Total heterotrophic count* were found in plant and crop product. The drip irrigation system used, which avoided the close contact between water and plant, may have contributed to this. Under the conditions applied in this study, the reuse of treated agro-industrial wastewater for irrigation can be considered an effective way to cope with agricultural water shortage in the Mediterranean area.

1. Introduction

A number of Mediterranean countries suffer from water scarcity, which has become severe in recent years due to global climate change causing frequent and long lasting periods of drought. Particularly during the summer, these areas experience severe water supply and demand imbalances. In the last decades, many Italian regions have faced the negative impact of drought and the resource scarcity has mostly penalized agricultural activities, which uses more than 50% of the total available water, while other high priority demands, such as those from civil and industrial sectors, are satisfied (Coppola et al., 2004). Particularly, in Apulia Region (South-Eastern Italy), water shortage has a serious impact on the local economy, mostly based on agriculture. Moreover, the agricultural coastal areas of Apulia Region suffer from relevant phenomena of seawater intrusion into the water table, due to the excessive and often uncontrolled groundwater withdrawals for irrigation (Libutti and Monteleone, 2012). For these reasons, alternative water sources are needed.

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Treated municipal wastewater is the most readily available source of water to meet the increasing demand for crop irrigation. Indeed, in recent years, wastewater recycling in agriculture has gained importance as component of agricultural water supply in several water-scarce countries (Qadir et al., 2007; Pedrero et al., 2010). Wastewater reuse not only provides significant amount of irrigation water, but also contributes to conserve potable resources and reduces the environmental impact related to the effluents discharge into water bodies (Aiello et al., 2007; Pedrero et al., 2010; Agrafioti and Diamadopoulos, 2012). Furthermore, soil application of treated wastewater also constitutes a reliable source of nutrients (especially nitrogen, phosphorus and potassium) and organic matter useful for maintaining the fertility and the productivity of the soil (Meli et al., 2002; Rusan et al., 2007). Treated wastewater use for crop irrigation can improve growth and yield of herbaceous species (Kiziloglu et al., 2008; Bedbabis et al., 2010) and can also enhance the economic benefits for farmers, due to reduced need for fertilizer (Bedbabis et al., 2010; Paranychianakis et al., 2006). However, the chemical composition of wastewater has to be monitored to avoid imbalance in nutrient supply, which may result in excessive vegetative growth, uneven fruit maturity, reduced quality and quantity of yields (Pedrero et al., 2010). Treated wastewater should be used for irrigation under controlled conditions, also to minimize hazards to agricultural products, soil and groundwater from toxic and pathogenic contaminants (Aiello et al., 2007; Qadir et al., 2007). Wastewater may contain a variety of pollutants, such as salts, heavy metals, organic compounds, enteric bacteria and viruses. An excessive accumulation of trace metals, such as Cd, Cu, Fe, Mn, Pb and Zn, in soils through irrigation creates problems for agricultural production (Singh et al., 2004) and leads to metal uptake by crops, so affecting food quality and safety (Khan et al., 2008). One of the crucial issues in the reuse of treated wastewater for crop irrigation is the residual presence of pathogenic microorganism (Rubino and Lonigro, 2008; Petterson et al., 2011) which represents a potential health risk to consumers when they enter in the food chain (Toze, 2006). In Italy, there are strict regulations for reclaimed wastewater reuse (Decree No. 152, 2006, Ministry for Environment), especially for levels of some chemical compounds and for microbial parameters. With regard to microbiological contamination levels, the corresponding guidelines allow unrestricted crop irrigation with a bacteriological effluent quality characterized by less than 10 CFU 100 ml^{-1} of *E. coli* in 80% of samples.

Several experimental evidences underline the effect on soil and yield of reclaimed urban wastewater application for vegetable and fruit crops irrigation in the Mediterranean area (Lonigro et al., 2007; Palese et al., 2009; Disciglio et al., 2014; Lonigro et al., 2015; Gatta et al., 2016). Our research activity focuses instead on treated agro-industrial wastewater reuse in agriculture. The reused agro-industrial wastewater was originated by an agricultural and food manufacturing company, which produces and processes vegetables, in Apulia Region (Southern Italy). Studies about the reuse of wastewater of agro-industrial origin for crop irrigation have been little evaluated and are poorly documented in literature. Recovery of this type of wastewater is instead of particular relevance in the Apulia Region where the economic system is strongly based on irrigated agriculture and characterized by a widespread presence of agro-food industries, whose activity annually releases large quantities of wastewater, usually discharged into torrents or rivers. Moreover, Apulia is one of the European regions most heavily affected by water shortage (Xiloyannis et al., 2002). In this contest, a careful management of agro-industrial wastewater for agricultural purposes represents a useful alternative to conventional water resources, allows to support irrigated agriculture, reduces costs and environmental impact of wastewater disposal. These advantages become even more useful when vegetable processing companies produce wastewater and grow the crops at the same site, as in the case study reported in this work. More specifically, the present paper reports the results of a 1.5-year research on irrigating vegetable crops with this type of water source, in Southern Italy. Two treatment schemes were applied to wastewater and the treated effluents were used for the irrigation of a test-field where processing tomato and broccoli crops were cultivated in close succession. With reference to the experimental trial described here, others papers, reporting the results of the first tomato crop cycle, have been already published (Disciglio et al., 2015; Gatta et al., 2015a,b). Unlike all these cited studies, which had the objectives to evaluate the effects of secondary treated agro-industrial wastewater on different soil and tomato crop yield characteristics, the present paper deals with the irrigation use of an additional treated wastewater type, such as the tertiary treated wastewater, and a longer experimental period, such as the succession of three cropping cycles, in order to assess: (i) the impact of treated wastewater on the main chemical properties of irrigated soil; (ii) the effects of treated wastewater on quantitative and qualitative aspects of crops yield; (iii) the risk of microbiological contamination of irrigated soil and the pathogen health risk of crop products.

2. Materials and methods

2.1. Study area and experimental site

The study was carried out in open field, from April 2012 to September 2013, in the north-west part of the Apulia Region (Southern Italy), at Stornarella (41° 15′N, 15° 44′E; altitude, 154 m a.s.l.), in the Foggia district. The area is characterized by a Mediterranean climate, with air temperatures that drops below 0° in winter and exceed peaks of 40 °C in summer. The long-term average annual rainfall is 590 mm, with precipitations unevenly distributed throughout the year and predominantly concentrated in the period from October to April (Caliandro et al., 2005). During the experimental period, the daily meteorological parameters, such as maximum and minimum air temperature (T_{MAX}, T_{MIN}), maximum and minimum air relative humidity (RH_{MAX}, RH_{MIN}), wind speed (W_S), and total precipitation (P) were recorded. These were measured by a weather station placed close to the experimental field and recorded using a data-logger (Campbell Scientific, USA).

The study area is characterized by a widespread presence of agro-food industries specialized in vegetables processing. The experimental site was located within the Fiordelisi agricultural and food manufacturing company. Fiordelisi's activity includes growing, processing, packaging and marketing of preserved, ready-to-eat vegetables, such as tomato, eggplant, zucchini and pepper. This activity involves the production of large quantities of wastewater that undergoes a purification process before being discharged according to local regulations. To this purpose, the Fiordelisi company is equipped with a wastewater treatment plant (WWTP). The WWTP was upgraded in order to produce effluents suitable for reuse, thus supplying the two types of treated wastewater used for crops irrigation during the experimental period, one produced by the conventional treatment system and the other by the upgraded configuration. The reclaimed water was then used within a closed-circle system where the wastewater produced as a by-product from vegetables processing becomes a water resource for vegetable crops irrigation, according to the criteria of recycling treated wastewater as a component of agricultural water supply, in water-scarce environmental conditions.

In the years 2012 and 2013, the Fiordelisi company produced about 100,000 m^3y^{-1} of wastewater, mainly composed of washing and processing water (vegetables cooking, steaming, bottles washing, etc.), water from cleaning floors and equipment, and toilet water (5–10%). The wastewater was purified in the WWTP