Agriculture, Ecosystems and Environment 192 (2014) 105–114

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Impact assessment of the reuse of two discrete treated wastewaters for the irrigation of tomato crop on the soil geochemical properties, fruit safety and crop productivity

Anastasis Christou[a,*], Grivas Maratheftis[a], Elena Eliadou[b], Costas Michael[b,c], Evroula Hapeshi[b,c], Despo Fatta-Kassinos[b,c]

[a] Agricultural Research Institute, P.O. Box 22016, 1516 Nicosia, Cyprus
[b] Department of Civil and Environmental Engineering, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus
[c] NIREAS-International Water Research Center, University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus

ARTICLE INFO

Article history:
Received 18 November 2013
Received in revised form 9 April 2014
Accepted 11 April 2014
Available online 5 May 2014

Keywords:
Electrical conductivity
Escherichia coli
Heavy metal content
Microbial assay
Tomato fruit
Transfer factor
Wastewater reuse

ABSTRACT

Advanced tertiary treatment and disinfection technologies have enabled the production of wastewater (WW) with quality complying with the established criteria for reuse in agriculture. This study assessed the impacts of tomato crop irrigation with two qualitatively distinct treated WW effluents, as compared to control tubewell water (TW) irrigation, on the soil geochemical properties, tomato fruit safety and crop productivity. The treated effluents reused for irrigation were produced in two Municipal Wastewater Treatment Plants (MWTPs) utilizing two discrete tertiary treatment and disinfection technologies, i.e. Slow Sand Filtration and chlorination (MWTP I), and Membrane Bioreactor and UV radiation (MWTP II), respectively. The impacts on soil pH, electrical conductivity, total organic C, Cl^-, NO_3^- and heavy metal (Zn, Mn, Ni, Cu, Co) content were evaluated. In addition, the heavy metal content in tomato fruits and leaves, as well as the microbial load in fruit flesh and peel was determined. Crop productivity was measured by the mean fruit weight and maximum diameter, and by the number of fruits per harvest. Irrigation with either WW did not significantly affect the soil pH, organic C and heavy metal content, as well as crop productivity, in comparison to control TW irrigation. Furthermore, the heavy metal content of tomato fruits and leaves in all irrigation treatments was found to be below the maximum permissible levels set for fruit safety and the critical tissue concentration for phytotoxicity, respectively. Moreover, no microbiological contamination (total coliform, fecal coliform, *Escherichia coli*, *Salmonella* spp., *Listeria* spp.) of tomato fruits was found from any irrigation treatment. Overall, results obtained with regard to the parameters examined strongly suggest that advanced tertiary treated effluent of good quality might be safely reused, in terms of both environmental sustainability and public health safety, for vegetable irrigation, concurrently promoting water use efficiency in dry areas.

1. Introduction

Quality fresh water for agriculture is becoming an increasingly scarce resource due to climate change effects and escalating competition from other water use sectors (Mesa-Jurado et al., 2012; Milano et al., 2012). Thus, wastewater (WW) reuse for irrigation represents an advantageous alternative for the mitigation of the ever increasing irrigation water scarcity and demand. Treated WW represents a potentially valuable, nutrient-rich and reliable source of water for the agricultural sector, available all year round (Hamilton et al., 2007). Therefore, WW reuse, mainly for irrigation, becomes increasingly important as an indispensible component of all integrated water recourses management schemes in arid and semi-arid areas around the world (Bixio et al., 2006; Angelakis and Durham, 2008). Although WW reuse for irrigation has gained an acceptance as an economic alternate that could substitute nutrient needs and water requirement of crop plants (Khurana and Singh, 2012), WW may contain undesirable chemical constituents and pathogens that pose negative environmental and health impacts (Muchuweti et al., 2006; Bernstein, 2011; Fatta-Kassinos et al., 2011). It is becoming widely accepted that WW reuse for irrigation, accompanied with the use of sewage sludge, constitute

* Corresponding author. Tel.: +357 22403113; fax: +357 22316770.
E-mail address: anastasis.christou@ari.gov.cy (A. Christou).

http://dx.doi.org/10.1016/j.agee.2014.04.007
0167-8809/

Table 1
Physico-chemical and microbiological analysis of the two MWTP's treated flows and the tubewell water abstracted from a borehole used for the irrigation of the tomato crop.

Parameter	MWTP I WW	MWTP II WW	Control TW	Irrigation water quality guidelines[1]
pH	8.19 ± 0.03	8.31 ± 0.04	8.45 ± 0.06	6.50–8.40
EC (mS cm^{-1})	1.71 ± 0.04	1.56 ± 0.03	3.13 ± 0.06	0.70–3.00[b]/>3.00[c]
BOD$_5$ (mg O$_2$ L^{-1})	5.00 ± 0.45	3.58 ± 0.21	0.98 ± 0.03	
COD (mg O$_2$ L^{-1})	36.67 ± 3.49	30.52 ± 1.23	7.09 ± 0.58	
SS (mg L^{-1})	4.38 ± 0.40	3.00 ± 0.45	0.53 ± 0.12	<50.00[a]
Total N (mg L^{-1})	7.38 ± 1.49	6.07 ± 1.19	0.61 ± 0.17	
Total P (mg L^{-1})	2.29 ± 0.14	0.70 ± 0.27	0.18 ± 0.02	
Cl$^-$ (mg L^{-1})	261.05 ± 3.73	317.70 ± 18.54	315.65 ± 23.06	
Zn (mg L^{-1})	0.04 ± 0.01	0.04 ± 0.01	0.11 ± 0.01	2.00
Mn (mg L^{-1})	0.03 ± 0.01	0.02 ± 0.01	0.01 ± 0.00	0.20
Ni (mg L^{-1})	0.04 ± 0.03	0.01 ± 0.00	b.l.q.[2]	0.20
Cu (mg L^{-1})	0.03 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.20
Co (mg L^{-1})	0.03 ± 0.00	0.01 ± 0.00	0.02 ± 0.00	0.05
E. coli (CFU 100 mL^{-1})	ND[3]	ND	ND	
Helminth eggs (egg L^{-1})	ND	ND	ND	

Data are the mean values ± standard errors (SE) of 5 samples taken during the tomato crop growing season.
[1] As set by the FAO's water quality for agriculture report (Ayers and Westcot, 1985).
[2] Below limit of quantification.
[3] Not detected (< 1CFU 100 mL^{-1} or < 1 egg L^{-1}).
[a] No restrictions.
[b] Slight to moterate restrictions.
[c] Severe restrictions for irrigation use.

the main causes of soil contamination with heavy metals and other pollutants (Li et al., 2009; Xu et al., 2010). Moreover, WW reuse may cause additional negative impacts, such as soil salinization (Klay et al., 2010), with salinity being recognized as a major factor reducing crop productivity worldwide (Krasensky and Jonak, 2012), and agricultural produce contamination with microbial and other anthropogenic pathogens (Sacks and Bernstein, 2011; Cirelli et al., 2012), if mismanagement and improper practices are taking place.

Several studies have recently documented an emerging risk concerning heavy metal accumulation in the topsoil of WW irrigated sites, worldwide (Mapanda et al., 2005; Li et al., 2009; Xu et al., 2010). Repeated WW applications may result in heavy metal accumulation in cultivated top-soil to toxic concentrations for plant growth (Megateli et al., 2009), while subsequent entry into the food-chain through various food crops and fodders represents the main pathway of human exposure to soil contamination (Rajaganapathy et al., 2011). Crop plants irrigated with treated WW have been found to absorb and accumulate excess heavy metals in the edible parts beyond maximum permissible limits (MPLs) (EC, 2001; WHO/FAO, 2007), set for guidance of their safety (Muchuweti et al., 2006; Khan et al., 2008; Singh et al., 2010a). Importantly, high levels of heavy metals in foodstuff evoke concern of potential chronic negative health impacts, in both children and adults (Szkup-Jablonska et al., 2012; Wang et al., 2012). Thus information about heavy metal concentrations, both in cultivated soils and agricultural produce, is very important for assessing the risks to public health. The presence of bacteria, such as *Escherichia coli*, and other human health related pathogens in WW irrigated crops' edible parts is also a potential concern (Petterson et al., 2001; Palese et al., 2009; Cirelli et al., 2012; Forslund et al., 2012). In this regard, comprehensive guidelines and criteria have been established in order to safeguard environmental sustainability and public health safety as a result of WW irrigation (WHO, 2006; Brissaud, 2008; U.S. Environmental Protection Agency, 2012). In addition, advanced WW treatment technologies have been developed, enabling contaminants and pathogens removal from treated WW (Fatta-Kassinos et al., 2010; Kalbar et al., 2012).

A holistic approach was employed in this study with the aim to assess the impacts of the reuse of effluents produced from two different WW treatment systems for the irrigation of a tomato crop, as compared to control tubewell water (TW) irrigation, on soil geochemical properties, fruit safety and crop productivity. The first treatment system includes Slow Sand Filtration (SSF) and chlorination, while the second one Membrane Bioreactor (MBR) and ultraviolet disinfection (UV). The two selected discrete technologies for the tertiary treatment and disinfection of WW are utilized worldwide, since they efficiently produce WW with a quality complying with the established criteria for WW reuse in agriculture, while simultaneously being cost effective (Meneses et al., 2010).

2. Materials and methods

2.1. Experimental design and treatments

Tomato seedlings were transplanted in a field dominated by sandy clay loam soil at the experimental station of the Agricultural Research Institute in Nicosia, Cyprus, in April 2012. Tomato plants were subjected to 3 treatments, based on the water source used for their irrigation. More precisely, treatments involved the WW irrigation of tomato plants with the tertiary treated effluent of MWTP I (MWTP I WW) and MWTP II (MWTP II WW), as well as control tubewell water irrigation (Control TW) with water abstracted from a nearby borehole within the experimental station. Tertiary treatment and disinfection in MWTP I is accomplished through SSF and chlorination process, whereas, in MWTP II through MBR and UV treatment, respectively. It is worth noting that these tertiary treatment and disinfection technologies are used in all WWTPs in Cyprus to produce 22 million cubic meters (MCM) of treated WW, from which nearly 65% (∼14 MCM) is reused for the irrigation of forage crops, citrus, olives and vegetables, as regulated by the Cyprus guideline for WW reuse. The chemical and microbial load of the three water sources used for the irrigation of tomato plants is presented in Table 1. The climate in the experimental region during the growing season is characterized by high temperatures (day light 30–40 °C; night 25–30 °C), and low relative humidity (less than 20%), having as a result high evapotranspiration rates. A completely randomised block design was applied, while each treatment was independently run in five replicates; each replicate consisted of 20 individual tomato plants. As a result 300 tomato plants were used in this experiment. Tomato plants were drip irrigated based upon direct measurements of soil moisture status (15 centibars) by the use of tensiometers. The tomato growing season lasted 150 d, and eight harvests took place.