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Treated municipal wastewater reuse in vegetable production

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ABSTRACT

Treated municipal wastewater (TWW) can be recycled and reused in Mediterranean countries and other arid and semi-arid regions that are confronting increasing water shortages. The evaluation of the long-term effects of treated wastewater reuse on crops intended for human consumption is of particular interest. This study presents the results of a reuse scenario where tertiary-treated municipal wastewater was supplied for vegetable crop irrigation (i.e., eggplant and tomato crops) in Eastern Sicily (Italy). The levels of faecal contamination of eggplants and tomatoes irrigated by surface and subsurface drip irrigation with urban TWW were analysed and compared in 2008 and 2009 at the experiment site. Irrigation water and fruit samples were collected during the two cropping seasons and evaluated for faecal bacteria (*Escherichia coli*, faecal coliform and faecal streptococci), *Salmonella* and helminth eggs. Soil samples were collected and evaluated for a hydraulic behaviour analysis. The study found elevated levels of *E. Coli* (*E. coli*) in the irrigation water, which were frequently above the stringent Italian mandatory limits of 50 CFU 100 mL^{-1} for secondary urban effluents treated at constructed wetlands. *Salmonella* and helminth eggs were never detected in TWW or on fruit samples. Only two eggplant samples, irrigated by surface drip irrigation, contained 10^2 CFU/100 g of faecal coliform and faecal streptococci. Maximum tomato contamination (on the order of 10^2 CFU/100 g for *E. coli* and 10^3 CFU/100 g for faecal coliform and faecal streptococci) was found on samples in contact with soil or plastic mulch, due to a significant increase of microbial biomass activity in these substrates. In the TWW irrigation scenario, maximum fruit yields of 38.5 and 89.7 t ha^{-1} were recorded during the two-year trial for the eggplant and tomato crops, respectively. Based on the production and quality components, the tomato crops were successfully grown on TWW-supplied plots, with higher yields (approximately 20%) than on plots supplied with fresh water. In particular, the use of subsurface drip irrigation resulted in a significant increase of the marketable yield (MY) for tomato crops, increasing the number of marketable fruits (MN) and decreasing the number of unmarketable fruits (UMN). The eggplants were sensitive to water-stress conditions resulting from partial clogging of the surface drip emitters, particularly those supplied by fresh water. During both the monitoring years, an induced water shortage caused high dry matter percentages for the eggplants.

The analysis of the reuse scenario confirms that, under controlled conditions, low-quality TWW can be used as an additional water resource to increase vegetable production in water-scarce Mediterranean environments.

1. Introduction

In Italy, particularly in its southern regions, water shortage is a serious problem that has a major impact on the local economy, which is mostly based on agriculture (Pollice et al., 2004). Excessive and uncontrolled groundwater withdrawals are causing significant sea intrusion into the water tables.

Inefficient water distribution networks supplying agricultural areas are the source of continual conflicts among different water users, and water quality degradation has exacerbated the increase in water demand. Alternative sources of irrigation water are needed. Treated municipal wastewater (TWW) is one of the most readily available alternative water sources when natural resources are limited. Although a lack of public acceptance has sometimes been a barrier to using this option, in recent years, the use of TWW has increased in water-scarce regions such as Pakistan, Mexico and Ghana, where a high percentage of the national crop production is irrigated with wastewater (Pedrero et al., 2010). In these areas, urban TWW reuse in agriculture is linked to micro-irrigation technology, which is a very effective strategy for making

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traditional agricultural production more cost-effective and water-efficient (Pedrero et al., 2010).

Italian legislation (n. 152/2006) states that natural freshwater sources should be used as a priority for the municipal water supply, and that the recycling and reuse of water are viable alternatives for meeting industrial and agricultural needs. Putting these strategies into practice requires that concentration limits, best treatment practices and irrigation technology options are defined to support TWW reuse in agriculture. These specifications are still under discussion; currently, there are strict regulations for TWW reuse (Ministry Decree, D.M. n. 185/03), especially for levels of some chemical compounds and for microbial parameters. In many cases, the quality standards for reclaimed wastewater are the same as for drinking water (Cirelli et al., 2008).

These regulations have made it difficult to promote TWW reuse, especially when advanced treatments are needed to ensure compliance with very strict standards, making water recycling uneconomical. Another obstacle is the excessive number of parameters (54) taken into account by the Italian legislation and their related monitoring protocols, which also have to comply with regional regulations. In addition, the legislation makes no distinction among different alternatives of TWW reuse, namely, urban non-potable, industrial and agricultural reuse. For agriculture in particular, the regulations do not distinguish between crops using restricted irrigation and those using unrestricted irrigation. Additionally, the regulations do not consider the impact of different irrigation options (i.e., subsurface drip irrigation versus spray irrigation) on reducing sanitation-related risks. In summary, current legislation is a major constraint to the development of municipal TWW reuse for irrigation in Italy.

In this framework, an experimental investigation has been performed to test the feasibility of tertiary-treated municipal wastewater reuse in agriculture. The study reports the results of two years of research on irrigating eggplant and tomato crops with municipal wastewater coming from a tertiary-constructed wetland treatment. This paper summarises the effects of irrigation with TWW on technological system management, crops and soil compared to a test system irrigated by conventional fresh water (FW).

Constructed wetland (CW) was adopted as a tertiary-treatment technology due to its low operation and maintenance costs and efficiency in treating wastewater from small and medium communities (Kadlec and Knight, 1996; Toscano et al., 2009). Generally, applied research on CW systems highlights the fact that treated municipal effluent directed to irrigation may contain readily absorbable useful nutrients and easily biodegradable organics, with an average effluent quality that is compatible with the limits on TWW discharge in water bodies imposed by the Italian regulations.

Table 1
Main characteristics of the selected soil samples collected during the field experiment (15–30 cm deep).

Parameter	Observed values	Optimal range
Sand (%)	20.8	–
Silt (%)	20.9	–
Clay (%)	58.3	–
$CaCO_3$ (g kg^{-1})	35.0	100/150
TN (g kg^{-1})	0.9	≥1
C (g kg^{-1})	11.0	≥20
pH	8.3	5.5/7.5
EC (μmS cm^{-1})	259.5	20/190
C/N	12.2	–

$CaCO_3$: calcium carbonate; TN: total nitrogen; C: organic carbon; EC: electrical conductivity; C/N: carbon to nitrogen ratio.

2. Materials and methods

2.1. Experimental field, soil hydrology and climatic parameters

The experiment was conducted in an open field near the CW system of San Michele di Ganzaria (Eastern Sicily, 37° 16′N, 14° 25′E) during two irrigation seasons in 2008 and 2009. The CW unit treats secondary urban effluents from the conventional wastewater treatment plant of the municipality (approximately 5000 inhabitants).

The area has a Mediterranean-arid climate. Rainfall (with a mean annual value of approximately 600 mm in 2008–2009) occurs mostly in the winter and is almost absent in the summer. The average mean daily temperature is 18 °C. The soil is clay (USDA textural soil classification, Table 1) with a volumetric soil content at field capacity of approximately 44% and a surface infiltration rate at the saturation level on the order of 10^{-3} cm/d. The main soil physical-chemical characteristics, as defined by Italian regulations (Ministry Decree D.M. n. 204/97 and D.M. n. 185/99), were measured at the beginning of the irrigation season of 2008 (Table 1).

The key meteorological variables (air temperature and humidity, rainfall, wind velocity and direction and solar radiation) were measured hourly by a weather station placed at the experiment site. Crop water requirements were estimated with the Class A pan evaporation method to determine evapotranspiration rates (ET_c.) (Allen et al., 1998).

2.2. Irrigation treatment and cultivation practices

The experimental system is described in Fig. 1. Hybrid F_1 'Black Bell' eggplant crops were transplanted at a density of 2.5 plants m^{-2} in 2008 and 3.0 plants m^{-2} in 2009; cultivar 'Missouri' tomato crops were transplanted at a density of 3.0 plants m^{-2} in 2009. Thus, two plots/crops were supplied by TWW and two were supplied by FW

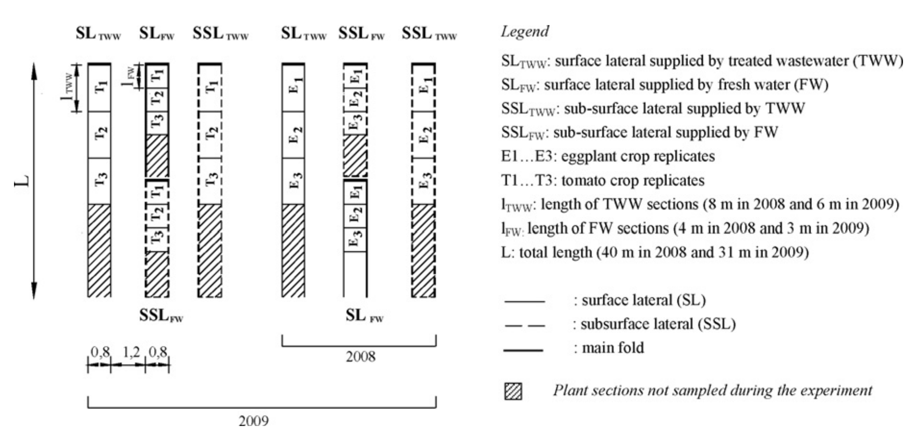

Fig. 1. Layout of the experimental irrigation system at San Michele di Ganzaria (seasons 2008 and 2009).