Ecological Engineering 107 (2017) 82–98

Contents lists available at ScienceDirect

Ecological Engineering

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

Research paper

Recycling of domestic wastewater treated by vertical-flow wetlands for irrigation of two consecutive *Capsicum annuum* generations

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ARTICLE INFO

Article history:
Received 25 April 2017
Received in revised form 28 June 2017
Accepted 2 July 2017
Available online 12 July 2017

Keywords:
Fruiting vegetable
Constructed wetland
Ecological sanitation
Biological treatment
Nitrogen
Total coliforms

ABSTRACT

Due to water scarcity, there is great interest in reusing various nutrient-rich wastewaters. The aim of this article is consequently to evaluate if domestic wastewater treated by various wetland systems can be successfully recycled to irrigate generations of commercial crops such as Chilli (*Capsicum annuum*) grown in compost within a laboratory environment to obtain a cultivar adapted to domestic wastewater. The corresponding objectives were to assess the irrigation water for long-term growth when applying recycled wastewater, the impact of various wastewaters subject to the wetland characteristics, the impact of treated wastewater volume for irrigation, and the economic return of different experimental set-ups in terms of marketable yields. The vertical-flow wetlands treated domestic wastewater well, meeting the irrigation water quality standards for most water quality parameters, except for phosphorus (4.2 ± 0.48 mg/l), ammonia-nitrogen (4.2 ± 2.64 mg/l), potassium (7.0 ± 3.03 mg/l) and total coliforms (69647 ± 64852.6 CFU/100 ml), which showed high values significantly ($p < 0.05$) exceeding common thresholds set for irrigation applications of 2 mg/l, 5 mg/l, 2 mg/l, and 1000 CFU/100 ml. Chilli generations were grown successfully when applying wastewater treated by wetlands and organic soil. High Chilli generation yields concerning economic return were linked with wetlands containing small aggregates with long contact and resting times and fed with a high inflow loading rate (undiluted wastewater), releasing more nutrients into their effluent producing the best fruit quality with respect to weight, length and width resulting in a greater marketable profit of about 46% compared with the others. First generation Chilli plants were grown with considerably shorter heights and produced abundant fruit numbers, which were harvested earlier than their mothers due to the reduction (approximately 55%) of irrigation water volume used for them compared to their mothers. However, excessive nutrients applied on mother plants via irrigation water resulted in better fruit quality regarding dimensions and weights compared with their corresponding first generation plants, leading to a greater marketable profit by about 25%.

1. Introduction

1.1. Background

Globally, freshwater scarcity is a growing challenge and natural water resources are becoming inadequate to fulfil demand due to economic development and an increasing population and (Huang and Xia, 2001). As the population increases, the need for food and water will continually grow. Due to this water scarcity problem around the world, it is essential to think about non-conventional water resources to satisfy the increased rates of demand for fresh water. Wastewater is an available alternative option to overcome the shortage in water supply resulting from previous discussed reasons, particularly population growth (Bichai et al., 2012; Noori et al., 2013; Almuktar and Scholz, 2015). Direct discharge of untreated wastewater to land and watercourses has a negative impact on human health (Khurana and Pritpal, 2012). Because of this, wastewater treatment and recycling methods will be vital to provide sufficient fresh water in the coming decades, since water resources are limited (FAO, 2003).

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http://dx.doi.org/10.1016/j.ecoleng.2017.07.002
0925-8574/

1.2. Constructed wetlands

Compared to conventional treatment systems, wetlands seem to be the technology of the highest promise in terms of pollutant removal and have advantages due to low maintenance cost and required energy (Vymazal, 2011). Furthermore, constructed wetlands are attractive to developing countries (Kivaisi, 2001). Constructed wetlands are treatment systems, encompassing biological, chemical and physical processes. These are rather comparable to processes occurring in natural wetlands. Constructed wetlands are commonly applied for pollution control, and may to treat industrial, urban and agricultural wastewaters (Sani et al., 2013; Scholz, 2010; Vymazal, 2011). Furthermore, constructed wetlands have a high rate of bio-chemical activity compared to conventional wastewater treatment systems, which allows conversion of many pollutants to non-toxic by-products. This low-cost technology not only reduces nutrients but also has a role in disinfection, rendering the treated wastewater to be used as a resource to irrigate crops in both developed and developing countries (Greenway, 2005).

Large-scale wetlands can be applied for the treatment of domestic wastewater (Dong et al., 2011). According to Belmont et al. (2004) and Wang et al. (2005), treatment of urban wastewater using wetland technology has been reported to be suitable for irrigation of plants due to meeting the specification of national guidelines. Moreover, constructed wetland systems showed high efficiency in removing most contaminants in domestic wastewater including chemicals (organic materials, heavy metals and trace elements) and microorganisms (bacteria, viruses and parasites) as reported by Kivaisi (2001) and Gross et al. (2007).

The application of treated wastewater for agricultural irrigation has much potential (Meda and Cornel, 2010), especially when incorporating the reuse of nutrients like nitrogen and phosphorous, which are important for plant production (Norton-Brandão et al., 2013). Furthermore, the application of various wastewater for irrigation purposes is another non-conventional water resource option, which is widely implemented in developing countries as well as in semi-arid developed countries due to the high stress on water resources (Smit et al., 1996; World Bank, 2000; FAO, 2003).

1.3. Recycling of treated wastewater for irrigation

The earliest documented sewage treatment units applying wastewater for agricultural use were constructed in the 16th and 17th centuries in Germany and Scotland (Shuval et al., 1986). The acceptance of wastewater recycling is due to an increase in pressure on water resources. Treated domestic wastewater can be recycled in areas with water scarcity.

There is a need to evaluate the impacts of treated wastewater recycling on cash crops (Asano and Levine, 1996; Aiello et al., 2007; Cirelli et al., 2012) due to the potential presence of harmful elements (Almuktar et al., 2015a, 2015b; Almuktar and Scholz, 2015, 2016a 2016,b). Cirelli et al. (2012) found unacceptable *Escherichia coli* levels in irrigation water. Aiello et al. (2007) reported on increased microbial contamination by *E. coli* and Faecal Streptococci on soil surfaces.

Boyden and Rababah (1996) successfully considered the potential of nutrient recycling from settled primary domestic wastewater to grow crops such as *Capsicum*. Cheng et al. (2004) promoted an integrated system treating wastewater from a pig farm to grow crops.

Morari and Giardini (2009) evaluated the treatment effectiveness of vertical-flow constructed wetlands applied for domestic wastewater. High suspended solids and total phosphorus outflows limited the recycling potential for irrigation applications. However, the same wetland type treating septic tank wastewater achieved good removal rates for key water quality parameters (Cui et al., 2003). This treated wastewater was successfully applied for hydroponic cultivation of vegetables, which had reduced nitrate concentrations. Removal efficiencies for total bacteria and coliforms utilising vertical-flow constructed wetlands comprising cinder substrate were high. Lopez et al. (2006) obtained promising results while assessing constructed wetlands treating domestic wastewater destined to be recycled by the agriculture industry.

Fig. 1. Experimental wetland set-up (Almuktar and Scholz, 2015, 2016a, 2016b).

1.4. Aim and objectives

Effluents from various wetland systems treating domestic wastewater were obtained to irrigate *Capsicum annuum* generations. The key aim is to assess, if *Capsicum annuum* seeds obtained from a related previous experiment (Almuktar et al., 2015a, 2015b; Almuktar and Scholz, 2015, 2016a, 2016b) can be cultivated with success on reused urban wastewater treated by wetlands compared to their original mother plants. The main objectives related to the Chilli generations are to evaluate (a) the suitability for their cultivation when applying reused urban wastewater, (b) the effect of various treated wastewaters subject to wetland characteristics, (c) the impact treated wastewater volume for plant growth, and (d) the economic feasibility of various experimental systems.

2. Materials and methods

2.1. Experimental wetland system and operation

The wetland set-up is located within an aerated greenhouse in Salford, UK (Sani et al., 2013; Almuktar and Scholz 2015, 2016a, 2016b). The rig (Fig. 1) was run between 27 June 2011 and 25 September 2015. The set-up comprised wetland controls receiving drinking water. Table 1 summarises the set-up (completely randomised design) testing four parameters. The impact of aggregate diameter is tested by comparing Filters 1 and 2 with Filters 3 and 4. Filters 5 and 6 compared to Filters 3 and 4 determines the effect of loading rate. Contact time is tested, if Filter 4 is compared with Filter 7. Resting time influences are assessed between Filters 7 and 8 (Table 1).

The ten wetlands were made of plastic pipes with an internal diameter of 19.5 cm and a corresponding height of 120 cm. The wetlands were filled with pea gravel up to a depth of 60 cm and planted with *Phragmites australis* (Cav.) Trin. ex Steud. (Common Reed). Dead macrophyte material was recycled by putting it on top of the litter layer (Sani et al., 2013). An outlet is located at the bottom of each pipe to allow for regulated outflow. The wetlands received 6.5 l of inflow (Table 1). Filters 1–6 were sampled after three days of contact time and subsequently left to rest for two days, while wetland 7 and 8 were sampled after three days of contact time and left to rest for two days and one day, respectively.