Agricultural Water Management 178 (2016) 12–20

Contents lists available at ScienceDirect

Agricultural Water Management

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

Effects of water managements on transport of *E. coli* in soil-plant system for drip irrigation applying secondary sewage effluent

Jiusheng Li, Jie Wen *

State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, 20 Chegongzhuang West Road, Haidian District, Beijing, China

ARTICLE INFO

Article history:
Received 19 April 2016
Received in revised form 31 August 2016
Accepted 31 August 2016

Keywords:
Pathogen
Lateral depth
Irrigation frequency
Asparagus lettuce

ABSTRACT

The two-year experiments presented in this paper aimed at investigating the effects of water management practices on transport of *E. coli* in soil and residuals in plants for drip irrigation while applying secondary domestic sewage effluent. In 2014, the experiments were designed with three lateral depth of 0 (S0), 10 (S1) and 20 cm (S2) below the soil surface along with three irrigation levels that were determined by pan coefficient of 0.6 (I1), 0.8 (I2) and 1.0 (I3). In 2015, three irrigation intervals of 4 days (F1), 8 days (F2) and 12 days (F3) along with three lateral depths similar to the 2014 experiments were used. Groundwater control experiments were applied for the treatments with pan coefficient of 0.8 (I2) in the 2014 and the irrigation intervals of 8 days in the 2015. The fate of *E. coli* in the soil was greatly influenced by lateral depth, and subsurface drip irrigation could avoid pathogen contamination when sewage effluent was applied. Surface drip irrigation more likely induced *E. coli* contamination on surface soil and the *E. coli* concentration demonstrated a decreasing trend after irrigation ceased. In general, a more frequent irrigation and a higher containing level of *E. coli* increased short term *E. coli* contamination of soil as it increased contacting opportunities between effluent and soil. However, the *E. coli* declined during an irrigation interval and was hardly detected three days after an irrigation ceased. On harvest, no *E. coli* was detected in the stems of asparagus lettuce and few counts of *E. coli* was detected on the leaves of the crop but a weak association between the irrigation management practices and *E. coli* contamination of leaves was found. Our study recommended that subsurface drip irrigation is a promising method to avoid *E. coli* contamination when applying sewage effluent.

1. Introduction

Water scarcity and droughts conditions are emerging as major issues worldwide (Bixio et al., 2006; Europea, 2007; FAO, 2012). It is estimated that more than 40% of the world's population will face water stress or scarcity within the next 50 years. In this context, the reuse of treated wastewater represents a valid option, in some cases urged by the absence of viable alternatives (Niemczynowicz, 1999; WHO, 2006). What is more, a significant proportion of treated wastewater is used for irrigation (Lazarova and Bahri, 2005; Wu et al., 2008).

Extensive use of reclaimed water for irrigation raised concerns about foodborne illness. Vegetables and fruits were generally colonized by a wide variety of microorganisms, such as bacteria, yeasts and fungi that could cause spoilage (Lindow and Brandl, 2003; Abadias et al., 2008). Lettuce, in particular, has been connected to several outbreaks of *E. coli* O157:H7. In July 1998, an outbreak of *E. coli* O157:H7 infections involving 40 Montana residents were associated with contaminated leaf lettuce (Ackers et al., 1998). The significance of fresh produce contamination as a vehicle for *E. coli* outbreaks was highlighted in 2006 when an outbreak of *E. coli* O157:H7 in the United States was linked to contamination of fresh-cut packaged spinach, which led to 205 confirmed illnesses and three deaths across 26 states (Centers for Disease Control and Prevention (CDC), 2006).

There are toxic chemicals and microbes in wastewaters or recycled water that usually pose threats to human health and environment. Bacteria including pathogenic *Escherichia coli* (*E. coli*), *Salmonella* sp., *Shigella* sp., *Campylobacter* sp., and *Listeria monocytogenes* in irrigation water may stay in soil or on the surface of crops, transmit to people and cause disease (USEPA, 2003). As one of the most common pathogenic bacteria that cause diseases in human, *E. coli* are consistently used as an indicator microorganism for the

* Corresponding author.
E-mail address: wenjie1985imau@163.com (J. Wen).

http://dx.doi.org/10.1016/j.agwat.2016.08.036
0378-3774/

risk assessment of microbial contamination (Foppen and Schijven, 2006).

Olaimat and Holley (2012) studied factors influencing the microbial safety of fresh produce and reported that inappropriate agricultural practices was one of the important factor that could cause foodborne illness. De Roever (1998) focused on microbiological safety evaluations and recommendations on fresh produce and pointed out Good Agricultural Practices (GAP) and Good Manufacturing Practices (GMP) were the first two elements which should be developed to provide guidance on those agricultural and processing steps that can reduce pathogen levels on fresh produce.

Irrigation methods influence bacterial transportation. Oliveira et al. (2012) have proved that *E. coli* O157:H7 survived in soil and lettuce leaves while applying contaminated water with surface and sprinkler irrigation. Drip irrigation has the priority in reducing the risk of bacterial contamination compared to furrow irrigation (Fonseca et al., 2011). Armon et al. (2002) reported that subsurface drip irrigation (SDI) could reduce the risk of crop contamination and direct exposure to farm workers when wastewater is used.

There is still lack systematic study on the effects of water management practices on transport of *E. coli* in soil and residuals within plants for drip irrigation while applying sewage effluent. The objective of this research was to study the effects of the drip irrigation regimes on *E. coli* distribution in soil planted with asparagus lettuce and E. coil residuals within plants when applying secondary sewage effluent through two seasons of greenhouse experiments. We also give recommendations for management of drip irrigation systems when applying secondary sewage effluent.

2. Materials and methods

2.1. Study sites

Two-season field experiments of asparagus lettuce under drip irrigation were applied from 28 August to 1 November in 2014, and from 3 April to 1 June in 2015, respectively. Both experiments were conducted in a solar heated greenhouse located at the Experimental Station of the National Center for Efficient Irrigation Engineering and Technology Research in Beijing (39°39′ N, 116°15′ E, and 31.3 m above sea level). In both seasons, the greenhouse was maintained opening at the bottom 0.3–0.5 m height during daytime of sunny day to create favorable environments for crop growth. The automated temperature/relative humidity data logger (HOBO U23-001, Onset Computer Corporation, USA) was used to record the environmental condition in the greenhouse. Fig. 1 gives temperature and humidity changes during the growing season of asparagus lettuce in both years. The temperature declined from 28.0 °C to 8.0 °C during the 2014 with an average daily temperature of 17.0 °C. The relative humidity fluctuated between 50.0% and 98.0% with an average daily value of 79%. In the 2015, the temperature ranged from 7.5 °C to 27.8 °C with an average daily temperature of 19.6 °C and the relative humidity fluctuated between 15% and 94% with an average daily value of 53%. These varying ranges of temperature and humidity during both seasons were suitable for the growth of the selected asparagus lettuce breed of thermo tolerant in spring and autumn according to local farmers' experiences.

The greenhouse was 50.0 m in length from north to south and 8.0 m wide from east to west. The soil was sandy loam (Fluvents, Entisols) with a bulk density of 1.33 g/cm^3 in 0–20 cm soil layer, and 1.45 g/cm^3 in 20–60 layers, and the average field capacity measured by the Wilcox method (Wilcox and Spilsbury, 1941) was 0.33 cm^3/cm^3.

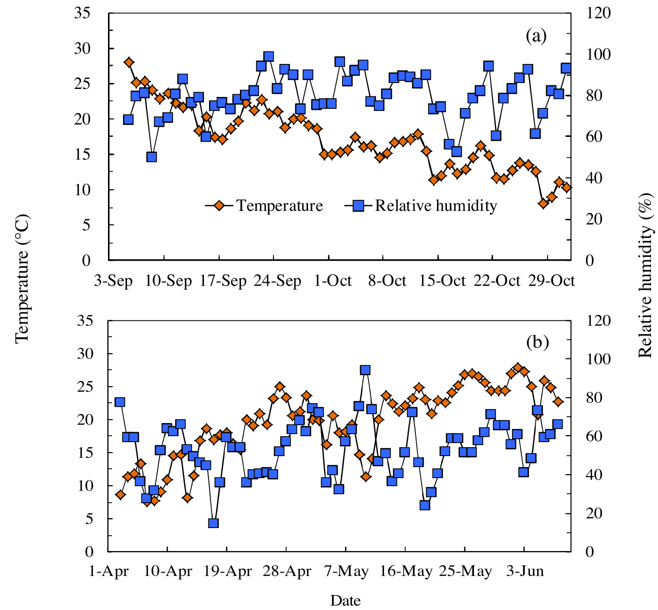

Fig. 1. The variation of temperature and relative humidity in the greenhouse during the growing season of asparagus lettuce in the 2014 (a) and the 2015 (b).

2.2. Experimental design

In the 2014 experiments, lateral depth, irrigation water applied and water qualities were considered. Three lateral depths of 0 cm (S0), 10 cm (S1), and 20 cm (S2) along with three irrigation levels that were determined by the accumulated pan evaporation of a 20 cm pan (DY ZF-1, Weifang Dayu Hydrological Science and Technology Co., Ltd., China) located at the top of the asparagus lettuce canopy multiplying by the pan coefficient of 0.6 (I1), 0.8 (I2) and 1.0 (I3). The pan coefficients used were determined by K_c values of lettuce published by Food and Agriculture Organization (Allen et al., 1998) and local research (Liu et al., 2013). When the accumulated evaporation of the 20 cm pan reached about 20 mm, an irrigation event was applied at designed pan coefficients. Additionally, control treatments irrigated with groundwater at pan coefficient of 0.8 (I2) were applied with lateral depths of 0 (S0), 10 (S1) and 20 cm (S2). Three replicates were used for each treatment, and a total of 36 plots were created randomly in the greenhouse.

As insignificant influence of irrigation level on the fate of *E. coli* in soil was observed in the 2014 season, the factor of irrigation level was changed to irrigation frequency in the 2015. Three irrigation intervals of 4 days (F1), 8 days (F2) and 12 days (F3) along with three lateral depths similar to the treatments in the 2014 experiments were used. The pan coefficient of 0.8 (I2) that was confirmed to produce a higher yield in the 2014 was used. Groundwater control experiments were applied for all the treatments with irrigation intervals of 8 days. Again, three replicates were also created for each treatment (Table 1).

Each plot was 2.7 m in length and 2.1 m wide. To obtain similar initial profiles in the different plots, about 100 mm of groundwater was applied to each plot by surface irrigation prior to seeding in both seasons to leach residual salts from the root zone. Four-leaf asparagus lettuce (*Lactuca sativa* L.) seedlings were transplanted at a row spacing of 0.35 m and a plant spacing of 0.3 m along a row on 28 August in the 2014, and on 3 April in the 2015. There were six rows of plants in each plot. Three driplines were installed along the median of two adjacent asparagus lettuce rows, and the two asparagus lettuce rows were irrigated by one dripline. The spacing between two adjacent driplines was 0.7 m. The dripline specially designed for SDI (TECHNET, Netafim Ltd., Israel) with emitters