Secondary wastewater disposal for crop irrigation with minimal risks

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Abstract A critical objective for any wastewater reuse program is to close the gap between supply of and demand for water and to minimize health and environmental hazards. Thus, the effects of treated effluent on crops, soils and community health must be considered carefully. When applying wastewater to soil-plant systems, it is to be noted that the passage of water through the soil reduces considerably the number of microorganisms carried out by the reclaimed wastewater. Nevertheless, there is a need to study the real rate of organism decay subject to water quality, soil and vegetable characteristics, and irrigation method. The aim of this work is to determine the fate of the fecal coliforms, coliphages F+ and CN13, and helminth eggs survival during the application of reclaimed wastewater in a vineyard orchard near the City of Arad (Israel) via onsurface and subsurface drip irrigation systems. Wastewater obtained from a stabilization pond, and soil samples were tested and an important decrease of microorganisms was reached in both cases, with the better values obtained with the sub-surface drip irrigation system.

Keywords Wastewater, reuse; pathogens; risks; onsurface drip; subsurface drip; effluent-soil-plant system

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Introduction

The continuous scarcity of water, primarily in arid and semi-arid regions, has promoted the search for extra sources currently not intensively exploited. The problem is intensified by a continuous reduction in water quality obtained from natural sources. The gap between supply and demand can be narrowed by substituting conventional water sources (e.g. fresh surface water and groundwater) by nonconventional water resources, like saline water, runoff water, reuse of treated municipal wastewater, and increasing the portion of high quality waters obtained by implementing extra filtration coupled with membrane technology (Brenner *et al*., 1995; Jolis *et al*., 1995; Oron, 1996). Along with improved control of the effluent quality, adequate reuse of even low quality domestic treated wastewater can play a significant role. Reuse of treated wastewater also solves disposal problems, while ameliorating water shortage, primarily during drought conditions.

Wastewater reclamation, recycling and reuse are in the general area of water resource systems and reflect societies increasing demand for water. They require implementation of advanced technology for water quality control, public acceptance, and improved understanding of public health risk (Asano and Levine, 1996; Rose and Gerba, 1991). Wastewater is unique in its composition, often being associated with environmental and health risks and its acceptability as a substitute for conventional or other non-conventional waters for irrigation or industry, is highly dependent on whether the associated health risks and adverse environmental impacts are within acceptable parameters (Angelakis *et al*., 1997; Gaspard and Schwartzbrod, 1995). The risk of environmental pollution and plant contamination during effluent reuse can be largely reduced by utilizing advanced application technology such as conventional onsurface drip irrigation (DI). Even when the wastewater is contaminated by viruses, DI and mainly Subsurface Drip Irrigation (SDI) systems are superior to other irrigation methods due to the minimal contact between the wastewater and the above surface exposed plant foliage and fruits (Oron *et al.*, 1991; Oron *et al.*, 1995). The SDI disposal technology may as well serve as an answer to the long-term and continuing debate regarding reuse criteria, mainly for regions where it is difficult to control effluent quality (Crook, 1998).

The fate of pathogenic microorganisms in soils and aquifer material is primarily governed by their transport and persistence in the soil medium environment. The survival and transport processes of pathogens in soils and aquifers are controlled by several major factors: (i) climate (temperature, rainfall); (ii) type of soil (texture, pH, water holding capacity, cation exchange capacity, organic matter content, salinity); and, (iii) type of pathogen (Bales *et al*., 1991; Bitton and Harvey, 1992; Gannon *et al*., 1991).

The purpose of this work is to present research findings obtained in commercial fields, providing information that under adequate irrigation technology, even low quality effluent can be utilized with minimal health and environmental risks. Determination of the fate microorganisms (bacteria, viruses and parasites) fate in the soil during the application of the reclaimed wastewater via DI and SDI systems allows confirming this hypothesis.

Pathogen removal mechanisms in soils and plants

As wastewater moves through the soil, bacteria are removed by straining, adsorption, and die-off processes. Clay in soils enhances adsorption. However, the small clay particles in the soils increase the straining of bacteria, primarily at the soil surface. Thus, it is frequently difficult to distinguish between the roles of straining and. adsorption.

Adsorption is a major factor in both survival and transport of viruses in the subsurface soil environment (Gerba *et al*., 1981). Factors influencing virus adsorption in the subsurface include (a) pH, organic matter content, aeration level, soil structure and texture, soil surface charge, and soil porosity and (b) virus size, surface charge, hidrophobicity and aggregation (Hurst *et al*., 1980; Lance, 1984; Meschke and Sobsey, 1998).

The pathogenic bacteria can survive on fruits and vegetables for from few days up to several weeks, depending on local conditions, weather, and the degree of contamination. Fecal coliform populations on alfalfa, irrigated with municipal sewage lagoon effluent, were rapidly reduced during the first 24 hours after application of sewage, under conditions of bright sunlight, low humidity and high temperatures. It has been suggested that viruses can persist for many days on plants**.** Limited data are available regarding virus penetration into the interior of plants, a process that probably requires even longer survival times (Ward et al, 1982). Additional pollution indicators included F+ and CN13 coliphages. Coliphages and bacteriophages are becoming common indicators for pollution levels and associated risks (Cai *et al*., 1988; Palmateer *et al*., 1991; Nasser *et al*., 1993).

Materials and methods

Field experiments

A field experiment is in progress in a vineyard located at a commercial farm near the City of Arad (Israel). The soil texture in the cultivated fields consist is of about 28.8% clay, 45.2% silt and 26% sand. The grapes were planted at a row spacing of 3.0 metres and an inter-row spacing of 1.5 metres. Each grape row (Merlot) is irrigated by one drip lateral. Two types of emitters and related spacings were used: emitters with a flow rate of 3.5 l/h were installed at 0.75 metres apart on the laterals. and emitters with a discharge of 2.3 l/h were spaced 0.5 m on the drip laterals. The orchard is irrigated once a week, with amounts subject to pan "A" evaporation and the development stage of the grapes. Two main treatments were examined: Onsurface Drip Irrigation (DI) and Subsurface Drip Irrigation (SDI). Both drip layouts were examined with tap water (control) and domestic effluent obtained from the stabilization pond system of the City of Arad.

Sampling

Wastewater and soil samples were taken during the irrigation period and examined for fecal coliforms, coliphages F+ and CN13 and helminth eggs. Soil samples were taken 25 cm away from the drip laterals on both sides, at the soil surface and at depths of 30, 60 and 90 cm, in order to measure vertical and horizontal distribution. Biological quality assessment of the health and environmental risks include microorganism content in the wastewater, soil and plants.

Laboratory analysis

The analytical methods followed were conventional. The chemical and biological analysis of the wastewater analysis was according to standard methods (APHA, 1995). The analysis for the coliphages, bacteriophages, viruses and helminth eggs follows different methods as mentioned elsewhere (Adams, 1959; Gaspard and Schwartzbrod, 1995; Campos, 1999).

Results

Wastewater and effluent quality

The effluent obtained from the stabilization pond system of the City of Arad is transported to a large reservoir (a capacity of around 0.5×10^6 m^3) and subsequently is applied for irrigation. The effluent quality hardly meets the Israeli secondary level reuse criteria (Table 1; ISQW, 1981). Frequently, a high content of nitrogen was observed, which might have adverse effects on the wine quality. The several high surges in potassium content are probably due to intermittent wastewater disposal from large adjacent laundries. The initial concentrations of the microorganisms in the wastewater were 10^6/100 ml for fecal coliforms, 10^3/100 ml for F+ coliphages, and 10^4/100 ml for CN13 coliphages, respectively.

Grapes yield and the application technology

After three years of irrigation with the SDI system the grape vineyard looked normal, and was similar to the sections irrigated with conventional onsurface drip irrigation systems. During the first experimental years, until the plants became adapted to the new irrigation system (SDI), insignificant differences were observed, primarily in the color of the plants and vegetative growth.

Table 1 Ranges of major constituents content (mg/l) of the wastewater (after the filter) applied for irrigation in Arad Heights during 1997 season

Constituent	Range
TSS	72–130
BOD_5	45–120
$N\text{-}NH_4$	34–58
Alkalinity as $CaCO_3$	330–495
Cl	204–260
PO_4	6.7–29.7
Na	180–270
K	26–90
EC, dS/m	1.50–1.80
SAR (–)	6.60–8.68
PAR (–)	0.41–1.41

The grape yield is based on manual harvesting, conducted during the end of August 1997. Prior to harvesting the maturation stage was continuously monitored. Harvesting was conducted in each replication, each of which consisted of 10 designated plants. The harvested sample was further used for wine production. The grape yield was significantly higher under SDI, regardless of water quality. Total yield during this experimental year, however, was to some extent lower than during previous years (Figure 1).

Effect of moisture content on pathogen survival in the soil

The microbial parameters determined (Figures 2, 5 and 6) show high performances of elimination of fecal coliforms and F+ and CN13 coliphages at different depths and distances from the emitter under onsurface and subsurface (drip lateral depth of 25 cm and 40 cm) drip irrigation (Figures 3 and 4). Moisture content was the most effective factor in pathogens survival. As indicated when moisture content in the soil was around "Field Capacity", around 20% by weight) than a significant reduction in all pathogens was noted. Total elimination of helminth eggs was established in all soil samples.

Effect of organic matter content on pathogens survival in the soil

The organic matter content in the soil examined is very important factor affecting pathogen survival. As indicated for this soil, when the organic matter content is above 0.85% a significant concentration of pathogens could be observed (Figure 5).

Effect of soil salinity on pathogens survival

Soil salinity contributed to fast decay processes of pathogens. As indicated when the soil salinity was higher than about 5 dS/m, a significant reduction in fecal coliforms was observed in the soil of the experimental plots (Figure 6).

In agreement with the results of other and similar research projects (Gerba *et al*., 1981; Lance, 1984; Nasser *et al*., 1993), the findings presented here clearly show a decrease of microorganisms when the wastewater filters through the soil. Virus removal by soil is believed to occur largely due to adsorption, in contrast with that of bacteria, which are removed by a combination of filtration, sedimentation and adsorption mechanisms.

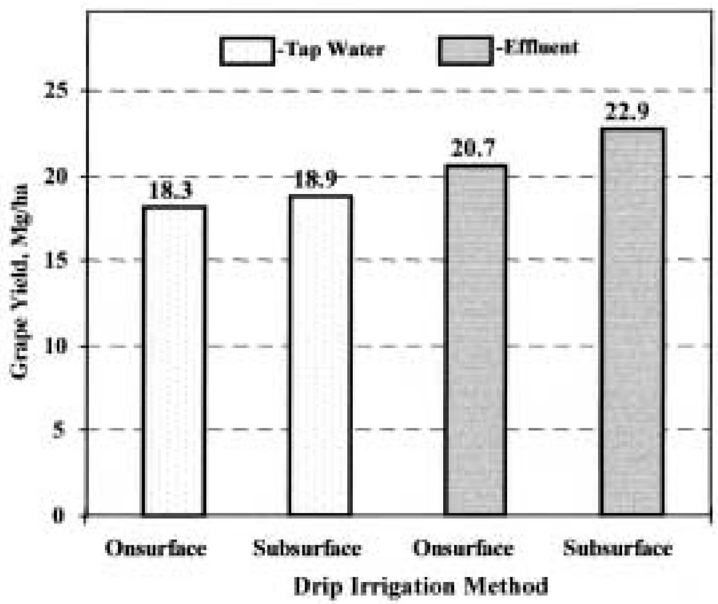

Figure 1 The grape yield in Arad Heights, summer 1997

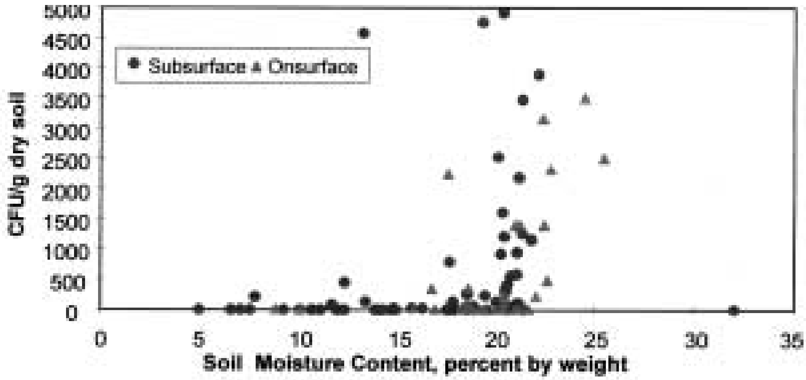

Figure 2 Fecal coliform *vs*. soil moisture content for onsurface and subsurface drip irrigation in Arad vineyard, summer 1997

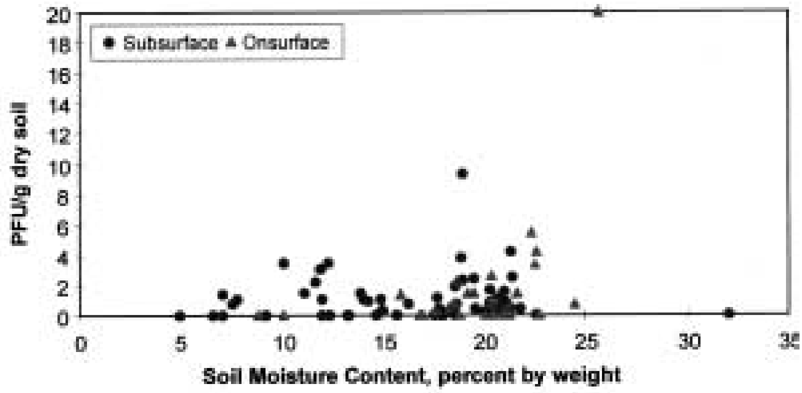

Figure 3 Coliphages F+ *vs*. soil moisture content for onsurface and subsurface drip irrigation in Arad vineyard, summer 1997

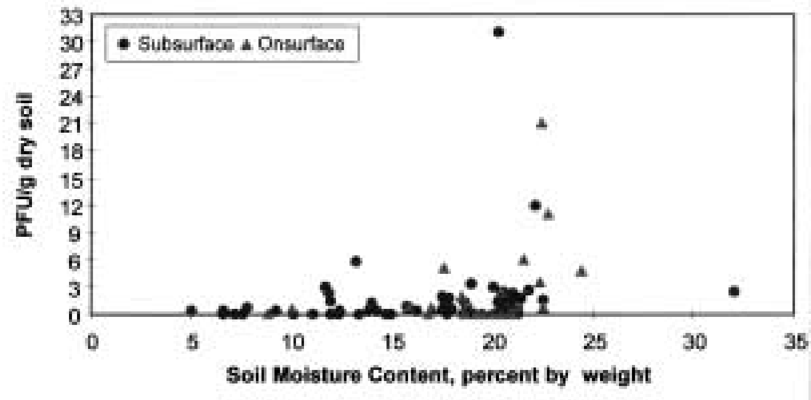

Figure 4 Coliphages CN13 *vs*. soil moisture content for onsurface and subsurface drip irrigation in Arad vineyard, summer 1997

Soil temperature and moisture are the primary factors affecting virus survival in soils irrigated with low quality effluent. Because of their small size, viruses are less subject to staining in soils than are bacteria. Virus adsorption to soils can be explained largely in terms of surface interactions between the amino acids on the capsid and the biological or nonbiological surfaces.

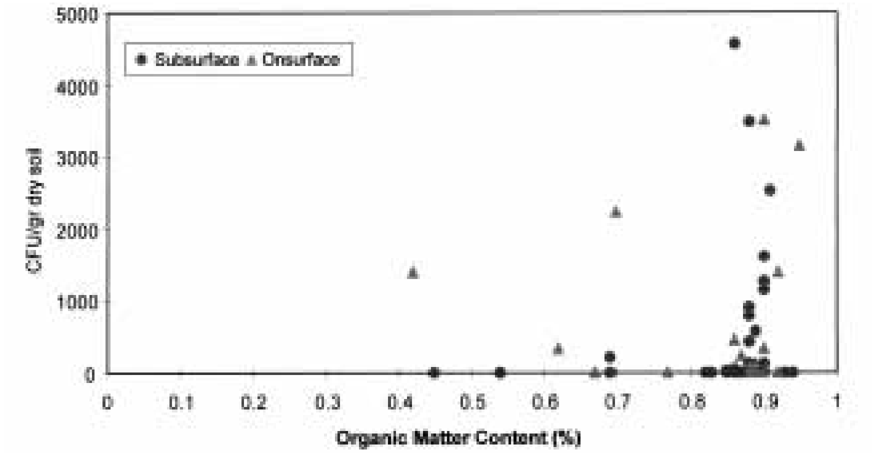

Figure 5 Fecal chloroforms *vs*. soil organic matter content for onsurface and subsurface drip irrigation in Arad vineyard, 7 July 1997

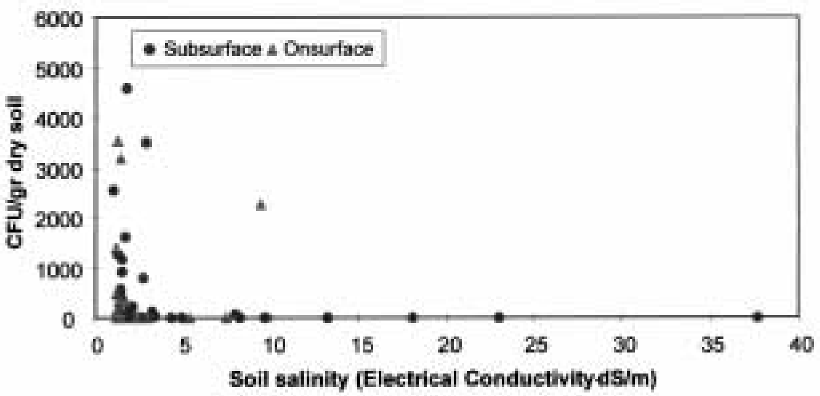

Figure 6 Fecal coliform *vs*. soil salinity (EC, dS/m) for onsurface and subsurface drip irrigation in Arad vineyard, 7 July 1997

Discussion and conclusions

The continuous experiments validated the assumption that prevailing conditions are the major influence over pathogen survival in the soil. When adopting disposal technologies that allow the effluent to remain in the soil media, with no exposure to workers or the onsurface foliage parts of the plants, the health and environmental risks can be diminished. This benefit is reinforced by the fact that only relatively small and controlled amounts of effluent are discharged for irrigation, thus the flow towards the deeper soil layers is minimized. The field findings lead to the following main conclusions.

1. The soil is capable of removing fecal coliforms, F + and CN13 coliphages, and helminth eggs used as fecal pollution indicators, when drip irrigation system is applied.
2. The application of secondary treated domestic wastewater in this specific soil and under these irrigation systems, affects the survival of microorganisms, thus reducing the health and environmental risk.
3. Further research is needed on establishing the relationship among soil characteristics and removal of the microorganisms, and the mechanisms, which explain the helminth eggs elimination with this kind of irrigation systems.

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