Behaviour of the fecal pollution indicators in a soil irrigated with treated wastewater under onsurface and subsurface drip irrigation

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Abstract A critical objective for any wastewater reuse programme is to minimise health and environmental hazard. When applying wastewater to soil-plant systems, it is to be noted that the passage of water through the soil considerably reduces the number of microorganisms carried by the reclaimed wastewater. Factors that affect survival include number and type of microorganisms, soil organic matter content, temperature, moisture, pH, rainfall, sunlight, protection provided by foliage and antagonism by soil microflora. The purpose of this work was to examine the behaviour of fecal pollution indicators in a soil irrigated with treated wastewater under onsurface and subsurface drip irrigation. The experiment was conducted in a vineyard located at a commercial farm near the City of Arad (Israel). Wastewater and soil samples were monitored during the irrigation period and examined for fecal coliforms, somatic and F+ coliphages and helminth eggs. Physico-chemical parameters were controlled in order to determine their relationship with removal of microorganisms. The results showed high reduction of the concentration of microorganisms when wastewater moves through the soil; and a good correlation between the reduction of fecal pollution indicators and moisture content, organic matter concentration and pH. The application of secondary treated domestic wastewater in this specific soil and under these irrigation systems affect the survival of microorganisms, thus reducing the health and environmental risk.

Keywords Drip irrigation; fecal pollution; moisture; organic matter; reuse; wastewater

Introduction

Pathogen removal mechanisms in soils

Because of the increasing emphasis placed upon land application as a means of wastewater disposal, it is important to evaluate the influence of different factors upon microorganism survival in soil. Viruses and other pathogens remaining in the sewage or sludge could contaminate crops, surface water or groundwater when applied to the soil (Hurst et al., 1980).

The major factors that control the persistence of enteric bacteria in the complex environment are temperature, moisture content, sunlight, pH, organic matter, bacterial type and antagonistic microflora. Straining which occurs within pores that are smaller than the limiting dimension of the cell, and adsorption onto particles are the major factors controlling transport of bacteria through soils. Because of their small size, viruses are less subject to straining in soils than are bacteria (Bitton and Harvey, 1992).

Virus survival increased as the soil moisture content increased up to the soil saturation point and some reports have indicated that dewatering by evaporation of sewage sludges containing viruses results in the inactivation of the sludge-bound viruses. The increased virus inactivation could be due to virucidal effects of the evaporative process per se as well as increased rates of virus inactivation at low soil moisture levels (Yeager and O’Brien, 1979).

The results from evaluating the effects of environmental variables on virus survival indicate that temperature is a significant predictor of virus survival. Straub et al. (1993) studied

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the virus survival under field conditions typical of the arid Southwestern United States. The average soil temperatures (measured at 10 cm depth) ranged from 15°C in the winter to 33°C in the summer. Soil moisture decreased from 25% to 15% in the winter and from 40% to less than 5% in the summer time. During the winter study, no inactivation of poliovirus was observed after seven days, while greater than 90% reduction was observed for MS-2. During the summer study, no poliovirus was recovered after seven days, and no MS-2 was recovered after three days. The results suggest that high soil temperature and rapid loss of moisture limit the survival of viruses in desert soils.

On the other hand, Gerba and Goyal (1981) found differences in adsorption between the different types and strains of viruses probably resulted from variability in the configuration of proteins on the outer capsid of the virus, since this could influence the net charge on the virus. The net charge on the virus would affect the electrostatic potential between virus and soil, and could thereby influence the degree of interaction between the two particles.

Virus survival is also influenced by certain soil characteristics. It decreased as a function of increasing soil pH and resin-extractable phosphorus. It was also reported that virus survival increased with increasing levels of exchangeable aluminium. The relative amounts of clay and humic minerals may also enhance survival. In general, both clay minerals and viruses are negatively charged. However, viruses do adsorb readily to clay minerals by electrostatic interactions, and the percentage of viral genome from attack by nucleases or other antagonistic factors in soil.

Laboratory studies with soils and batch experiments with suspensions of soil or clay have shown that the ionic composition of the water containing the added viruses is a very important factors affecting virus adsorption. It appears that virus adsorption may be proportional to the ionic strength of the solution. The iso-electric pH for most enteric viruses is below pH 5.0. Since this is below the pH range of most soils, both the viruses and soils usually have a net charge. Thus, viruses are not bounded to soils by ion exchange type reaction, except in highly acid soils (Wallis et al., 1972).

Drip irrigation system

The versatile filtration properties of the soil can be utilized for secondary effluent disposal. Effluent discharged intermittently from an underground slow release point source (approximately 30 to 50 cm below the soil surface) is subject to a series of complementary biofiltration and purification processes and does not reach the soil surface.

These are typically the conditions for subsurface drip irrigation. Essentially, by disposing the effluent in the soil bulk, close to the root zone, most of it will be absorbed by the plant and only a negligible fraction will percolate towards the groundwater. The possibility of the effluent reaching the soil surface is minor, owing to gravitational effects and the controlled non-continuous injection. Hence, subsurface drip irrigation can be considered a complementary phase to secondary wastewater treatment. Although, under onsurface drip irrigation, the exposure of the effluent to direct solar radiation and high temperatures might enhance the die-off of pathogenic contamination organisms, the risk of direct contact with the effluent is still relatively high (Oron et al., 1992; Oron, 1996).

The objectives of this work were to: (i) examine the behaviour of fecal pollution indicators (fecal coliforms, F+ and somatic coliphages and helminth eggs) in a soil irrigated with treated wastewater under onsurface and subsurface drip irrigation; and (ii) determine the relationship between the decrease in microorganisms and the physico-chemical characteristics of the soil.

Methods

The experiment was conducted in a vineyard located at a commercial farm near the City of Arad (Israel). The grapes were planted at row spacing of 3.0 metres and inter-row spacing of
1.5 metres. Each grape row is served by one drip lateral. Emitters with a flow rate of 3.5 l/h and 2.3 l/h were installed at 0.75 metres and 0.5 metres apart, respectively, on the laterals. The orchard is irrigated once a week. Two treatments were examined: onsurface and subsurface (drip lateral depth of 25 cm and 40 cm) drip irrigation both with effluent from a stabilization pond system.

Wastewater and soil samples were monitored during the irrigation period and examined for fecal coliforms, F+ and somatic coliphages 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. The soil texture in the cultivated fields consists of around 28.8% clay, 45.2% silt and 26.0% sand.

The soil samples were analyzed for physico-chemical parameters (pH, conductivity, moisture, organic matter, CaO, K₂O, MgO, Na₂O, N–NH₄, HCO₃ and P₂O₅), in order to know the relationship between concentration of the microorganisms and the soil characteristics. The rate of fecal indicators reduction was evaluated statistically with regard to the soil characteristics. This relationship was determined by regression analysis, using the Statistical Package for the Social Sciences (SPSS) computer program.

Results and discussion
The initial concentrations of the microorganisms in the wastewater were 10⁶/100 ml for fecal coliforms, 10⁴/100 ml for F+ coliphages and 10⁴/100 ml for somatic coliphages. One day after irrigation the concentration of fecal coliforms was (10⁳/g dry soil for onsurface and subsurface systems (25 cm depth). When emitters were placed at 40 cm depth the concentration was 10²/g dry soil. F+ and the somatic coliphage concentration was reduced to 10¹/g dry soil in both coliphages and for the two irrigation systems. These results showed that soil performs as an efficient barrier, thus decreasing microorganisms concentration and therefore sanitary risk. The soil analysis did not reveal the presence of any helminth eggs.

The factors that were found to influence fecal indicators survival were moisture content, organic matter concentration, and pH. Conductivity, K₂O, HCO₃ and N–NH₄ were statistically significant only for fecal coliforms or bacteriophages. The other parameters were not statistically significant (Table 1). This is in agreement with the work of many research groups who have evaluated the survival of microorganisms in the environment.

The survival results for various experimental conditions are shown in Figures 1, 2 and 3 on a scale for various moisture contents from the soil. It appeared from these plots that moisture content had a large effect on survival of the fecal coliforms and F+ and somatic coliphages, with reduction rates increasing as moisture content decreased. These results are similar to those obtained by Straub et al. (1992).

Table 1 Regression analysis for the soil characteristics and fecal indicators concentration

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Fecal coliforms*</th>
<th>F+ coliphages*</th>
<th>Somatic coliphages*</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>0.034</td>
<td>0.088</td>
<td>0.012</td>
</tr>
<tr>
<td>Moisture</td>
<td>0.006</td>
<td>0.073</td>
<td>0.013</td>
</tr>
<tr>
<td>Organic matter</td>
<td>0.018</td>
<td>0.062</td>
<td>0.098</td>
</tr>
<tr>
<td>Conductivity</td>
<td>0.002</td>
<td>0.090</td>
<td>0.148</td>
</tr>
<tr>
<td>CaO</td>
<td>0.628</td>
<td>0.214</td>
<td>0.262</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.896</td>
<td>0.101</td>
<td>0.098</td>
</tr>
<tr>
<td>MgO</td>
<td>0.784</td>
<td>0.206</td>
<td>0.313</td>
</tr>
<tr>
<td>HCO₃</td>
<td>0.004</td>
<td>0.031</td>
<td>0.662</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.268</td>
<td>0.370</td>
<td>0.743</td>
</tr>
<tr>
<td>N–NH₄</td>
<td>0.004</td>
<td>0.115</td>
<td>0.120</td>
</tr>
</tbody>
</table>

*Significance P ≤ 0.05 and between 0.005 and 0.1
The effect that soil pH was found to have upon virus survival might be mediated through virus adsorption to the soil. It has been found in several studies that soil pH is the major variable affecting adsorption of viruses to soil, with adsorption increasing as pH decreased (Hurst, 1980; Gerba and Goyal, 1981).

Powelson et al. (1992), found that agricultural cultivation also increases the release of organic compounds in soluble forms. Furthermore, organic matter concentrations normally decline with depth, many organic matter molecules are strongly retained to soils by hydrogen bonding, Van der Waals attraction, or other forces. The sorbed organics may then biodegrade before reaching a great depth (Powelson et al., 1991).

The fact that adsorption of viruses to soil significantly affects virus survival is of great importance. This finding indicates a dilemma insofar as virus inactivation during land treatment is concerned. On the other hand, concern for public health would, of necessity, require
that land treatment, be developed on soils with high virus adsorptive capacity. The adsorption depends on pH, organic matter content, strain and flow rate.

Conclusions
The application of wastewater under onsurface and subsurface drip irrigation shows a high degree of microorganisms decay. Microorganism removal increases in both systems with depth and distance from the emitter but is higher in the subsurface drip irrigation system.

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. The survival and transport of pathogens in the soil are controlled by the soil ecology, type of soil, organic matter content, pH and percentage of moisture.

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

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