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Nutrient Fate in Treated Wastewater Amenity Irrigation

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The use of treated wastewater for irrigation can be traced as far back as 300 BC when Greek farmers used wastewater from the city to irrigate and fertilise crops. Agricultural irrigation with municipal wastewater and raw sewage is extensively used in China, India, and many other countries, often leading to serious contamination. The nutrient content of municipal and industrial wastewater makes it very attractive for use as fertilizer and soil conditioner as well as serving as an important supply of water. If the significant risks of contamination associated with the use of wastewater for irrigation can be overcome, then such recycling will be beneficial for both economic and agricultural development (Stagnitti et al 1998, 2003).

Leaching of nutrients through the soil into groundwater aquifers and in turn into water courses fed by groundwater is currently a major hurdle to the use of wastewater and sewage irrigation. The long-term sustainability of agricultural soils may also be threatened by the increased amount of salts in the wastewater irrigation. Drinking water supplies may also be at risk. In order to better manage this potential resource, one needs to carefully understand how the nutrients in the irrigated water are transported through the soil because the use of reclaimed wastewater may lead to degradation of soil aggregate stability, a decrease soil hydraulic conductivity, increase surface sealing, increase runoff and soil erosion, increase soil compaction, and decrease soil aeration (Levy et al 1999). In a recent feasibility study for the Balliang district recycled water project, Melbourne Water (2003) recognised that "using recycled water for irrigation may pose a risk to the irrigated soil structure over time and this will need to be carefully managed" when considering salts, nutrients and pathogens. "Key messages to the public will deal with the development of innovative and sustainable irrigation, the benefits of recycled water, the economic benefits to local people, and increased land productivity" (Melbourne Water 2003).

The aim of this paper is to present the results of a leaching experiment using a typical wastewater stream on a typical soil.

MATERIALS AND METHODS

The Environment Protection Authority (EPA) Victoria, Australia has established four categories of recycled water. Each category has a recommended level of treatment and range of uses (EPA Victoria 2002). Class A reclaimed water requires tertiary treatment and pathogen reduction. This wastewater can be used for urban (non-potable, uncontrolled public access), agricultural (human food

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which can be consumed raw), and industrial (open systems). Class B reclaimed water requires secondary treatment and pathogen reduction and can be used for agricultural (dairy cattle grazing) and industrial (washdown water). Class C reclaimed water requires secondary treatment and pathogen reduction and can be used for urban (non-potable, controlled public access), agricultural (human food which must be cooked or processed before being consumed), grazing/fodder for livestock, and industrial (with no potential exposure to workers). The last category, class D reclaimed water requires only secondary treatment and can only be used for agriculture that involves no food crops. A Class A standard has been recommended for the Balliang demonstration project and therefore is used in this study.

The flow of water through soil can generally be divided into two types; preferential flow and matrix flow (Stagnitti et al 2003). Matrix flow is a relatively slow and uniform movement of water and solutes though the soil while sampling all pore spaces. In contrast, preferential flow is the non-uniform and often rapid movement of water through soils. This rapid movement bypasses the bulk of the soil matrix, reducing the potential for nutrient adsorption and/or degradation and often increasing the threat of groundwater contamination (Stagnitti et al 2003). Preferential flow can be attributed to structural voids in field soils including wormholes and cracks. Too often, soil leaching studies are conducted on reconstructed, repacked soils which destroy the natural structure of the soil and hence reduce the potential for preferential flow. We chose to use soil samples collected from a field site containing a typical top soil. The treated wastewater was applied to the soil columns using an X-Y raster-scanning, drip irrigation system controlled by two stepper motors as described in Stagnitti et al (1998). The irrigation system was connected to a variable speed peristaltic pump to control the amount of water delivered on the soil surface.

There are a number of sampling methods presently in use for leachate experiments. These include soil cores, porous cup sampling, pan sampling, wick sampling and tile lines (Boll et al 1992). The most relevant testing for the purposes of this experiment is the wick sampling method (Boll et al 1992, Stagnitti et al 2003). Figure 1 illustrates the experimental design for this study. The collection baseplate consists of four individual collection wells of identical size, approximately 6 cm by 6 cm, with a 1 cm hole in the middle of each well for the wick (see figure 1a). Once the springs and steel plate were attached to the baseplate, approximately 15 cm of each fibreglass wick was teased out and glued to the top of the plate (see figure 1b and 1c). The remaining length of wick (approximately 30 cm) hung through the spring and baseplate. The wicks were encased in plastic tubing to reduce the amount of evaporation from the wick surface (see figure 1d). Once the springs, plates and wicks were attached, the baseplate was then sealed from the inside of the 30 cm PVC soil sample cylinder and approximately 30 cm soil sample was placed above the sample unit. The purpose of the wick was to provide a comparable suction (capillary force to the top soil) so that unsaturated flow can be sampled. The reason for having four collection wells rather than one was to reduce the solute travel-time (Boll et al. 1992). Also having 4 wells provided a better measure of preferential flow (Stagnitti et al 2003). A nonwoven, polypropylene geotextile (Geotextile Filter Design 1, Mirafi, 2004ab) suited for filtering, drainage and erosion control in clayey-sand, sandy-silt and lean-clay soil types was used to separate the soil from the steel plate. A double layer of the geotextile fabric, for extra filtering, was cut to size and sat on top of the wicks.

Two soil columns were used to determine leachate nutrient contents. One soil column was treated with wastewater and the other with tap water.

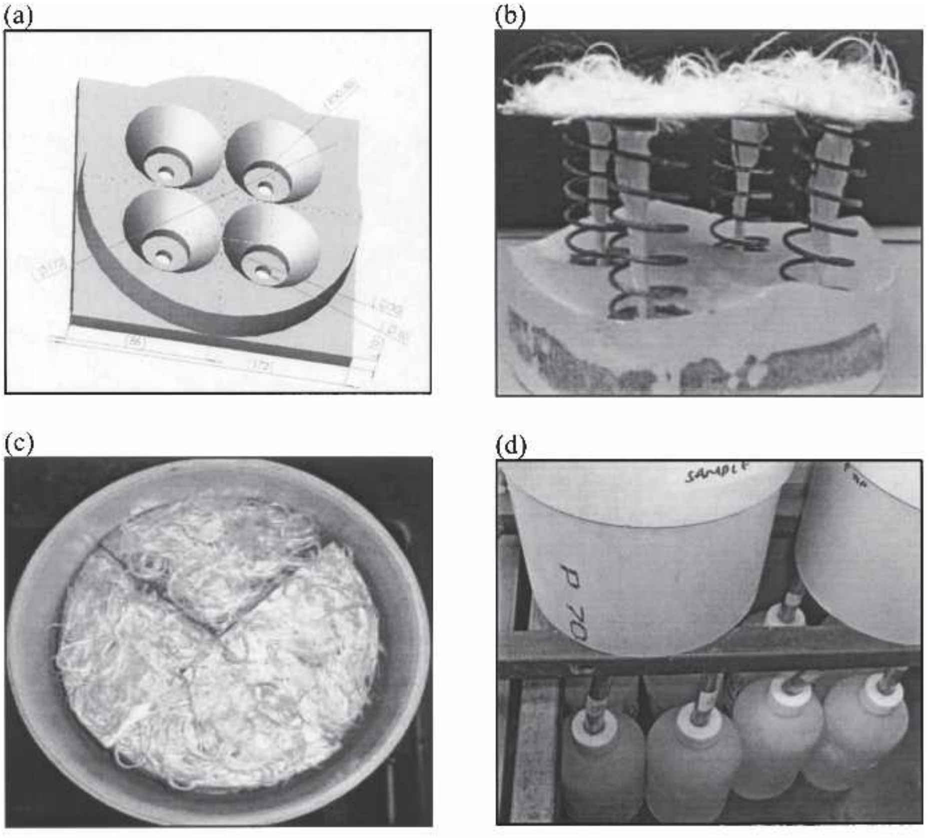

Figure 1. Experimental design of soil-water sampler. (a) Diagram of basal plate with 4 collection wells, (b) Side view of sampler with springs and wicks. (c) Top view showing teased-out wick at the soil column end. (d) 30cm PVC outer cylinders containing soil sample and one-liter plastic leachate collection bottles.

The tap water experiment provided results on the background concentrations of nutrients in the soil. An initial estimate of the flowrate was taken from a theoretical hydraulic conductivity value for the soil. Then, prior to the leachate experiment, a test soil column was used to determine the most appropriate flowrate by slightly adjusting the peristaltic pump to ensure optimal unsaturated conditions within the soil. Due to the amount of sediments and colour in the soil, the leachate needed to be centrifuged for 20 min prior to filtering. The centrifuged sample was first passed through a 47 μm and secondly a 0.2 μm filter under vacuum pressure to remove as much of the sediments and colour before the sample was analysed.

The wastewater was collected from the South Ballarat Treatment Plant run by the Central Highlands Water in Ballarat, Victoria. The treated wastewater, once it had passed through the secondary clarifiers, was stored in 15 L plastic containers. The DO was tested on site at the time of collection. The wastewater was taken to Deakin University's environmental laboratories on the Geelong campus and was stored in a refridgerator until required. Tap water, taken from the environmental laboratories at Deakin University, also was stored in a 15 L plastic container. The initial concentration of chloride, total nitrogen and phosphate of both the wastewater and the tap water was determined. The soil surface was irrigated with tap water or wastewater. Over a sixteen-day period the leachate was measured and collected every twenty-four hours, at approximately the same time each day. A volume of 50 mL of leachate was required for nutrients analyses. If the volume of leachate was too small (i.e. less than 50 mL), the sample was left and taken in the next twenty-four hour collection. The averaged leachate data (for chloride, total nitrogen and phosphate) was used to develop breakthrough curves – highlighting the concentration of nutrients over time, traveling through the soil.

RESULTS AND DISCUSSION

The transport of salts and nutrients (chloride, phospate-phosphorus and total nitrogen) through a typical topsoil used in Australian gardens and landscaping following irrigation with Class A wastewater is described. Studies of this nature will be of importance as governments in both developed and developing nations search for new sources of water, fit for purpose, and will be increasingly reliant on wastewater as an alternative means of supply.

The wet and dry method for determining the grain size distribution of the imported top soil was used. The results for both wet and dry sieving were found to be very similar; therefore an average grain size distribution was determined. Figure 2 presents the particle size distribution for the soil. The average distribution of grain size is between sieve apertures phi scale 2 and 3, equivalent to 125 and 250 μm respectively.

Before the leachate was analysed for nutrients, it was collected from the four separate bottles and their individual volumes were recorded. Figure 3 shows the effluent volumes for the wastewater treatment for the duration of the experiment. Even though the inflow rate distribution across the soil surface was uniform, the leachate collected in each bottle was not. After an initial peak in the first two days, the volume of leachate collected in each bottle was relatively similar. It was not until the last few days that the volume of leachate collected became irregular and then too small to sample. This feature of the data illustrates the dynamic nature of soil-water flow in soils and confirms the need to collect many samples to obtain a representative view of solute transport.

The chloride concentrations for tap water and tap water treated leachate were 50.02 mg Cl^-/L and 212.72 Cl^-/L respectively. These values can be compared with the treated wastewater chloride concentrations which are shown in Figure 4. After an initial peak of approximately 980 mg Cl^-/L in the treated wastewater leachate, the concentration of chloride levelled out to values ranging between 170 and 210 mg Cl^-/L. The concentration of total nitrogen in the tap water was very low, but the concentration in the tap water leachate was quite high, with values of 0.8 mg/L and 6.9 mg/L recorded respectively.

These values were compared with the nitrogen concentrations of the treated wastewater samples as shown in Figure 4. The phosphate concentration of the tap water was 0.78 mg/L and the tap water leachate 3.1 mg/L. The concentration in the treated wastewater sample varied from 0.5 to 1.2 mg/L.

The average breakthrough curves (BTC) for chloride, total nitrogen and phosphate are shown in Figure 5.

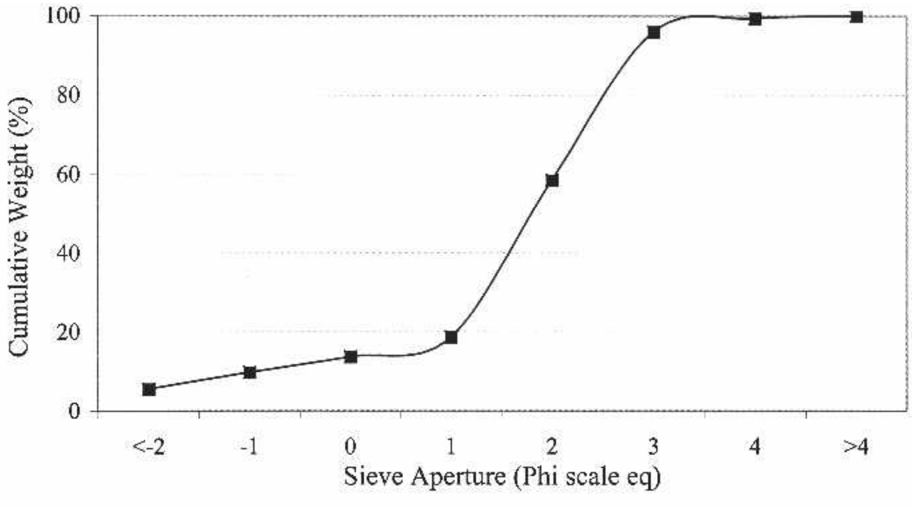

Figure 2. Topsoil particle grain size distribution.

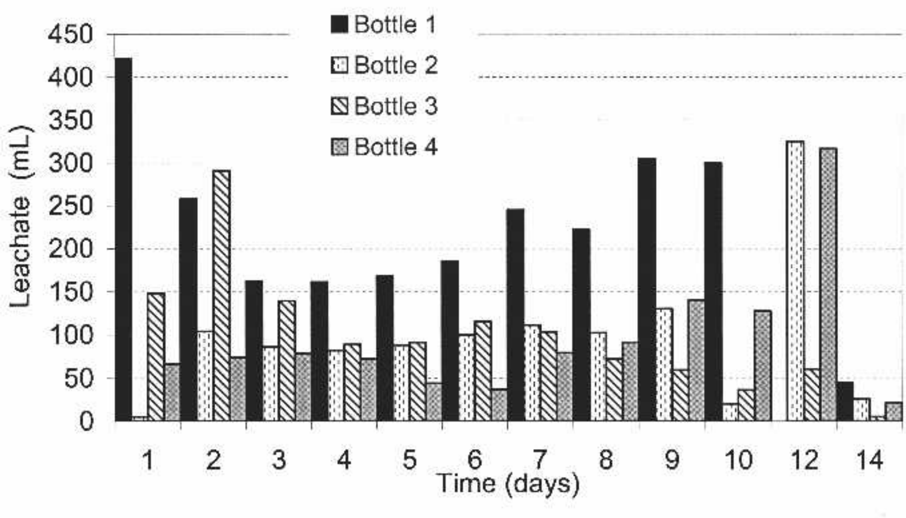

Figure 3. Volumes of treated wastewater leachate collected over the duration of the experiment.

In Figure 5, the scaled concentrations are presented, i.e. C/C_0, where C represents the concentration of the nutrient divided by the initial concentration C_0, which was determined from the averaged tap-water leachate concentration. The averaged scaled concentration is also presented in the figure. The BTCs show that approximately 55% of chloride, 63% of nitrogen and 24% phosphorus is leached from the soil column. After day 10 both the nitrate and phosphorus concentration rises.

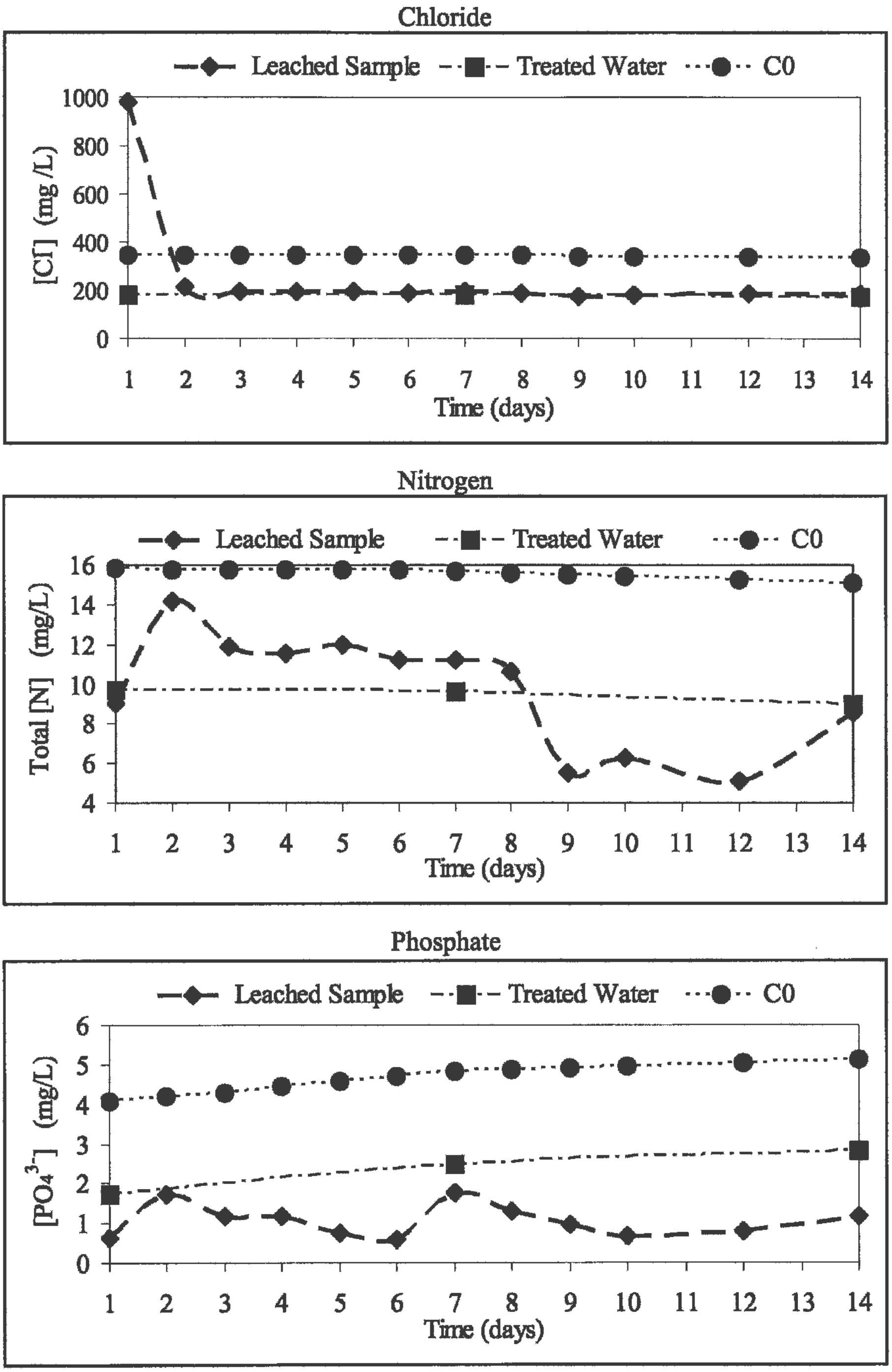

Figure 4. Treated wastewater leachate from soil column showing chloride, total nitrogen and phosphate concentrations, respectively.

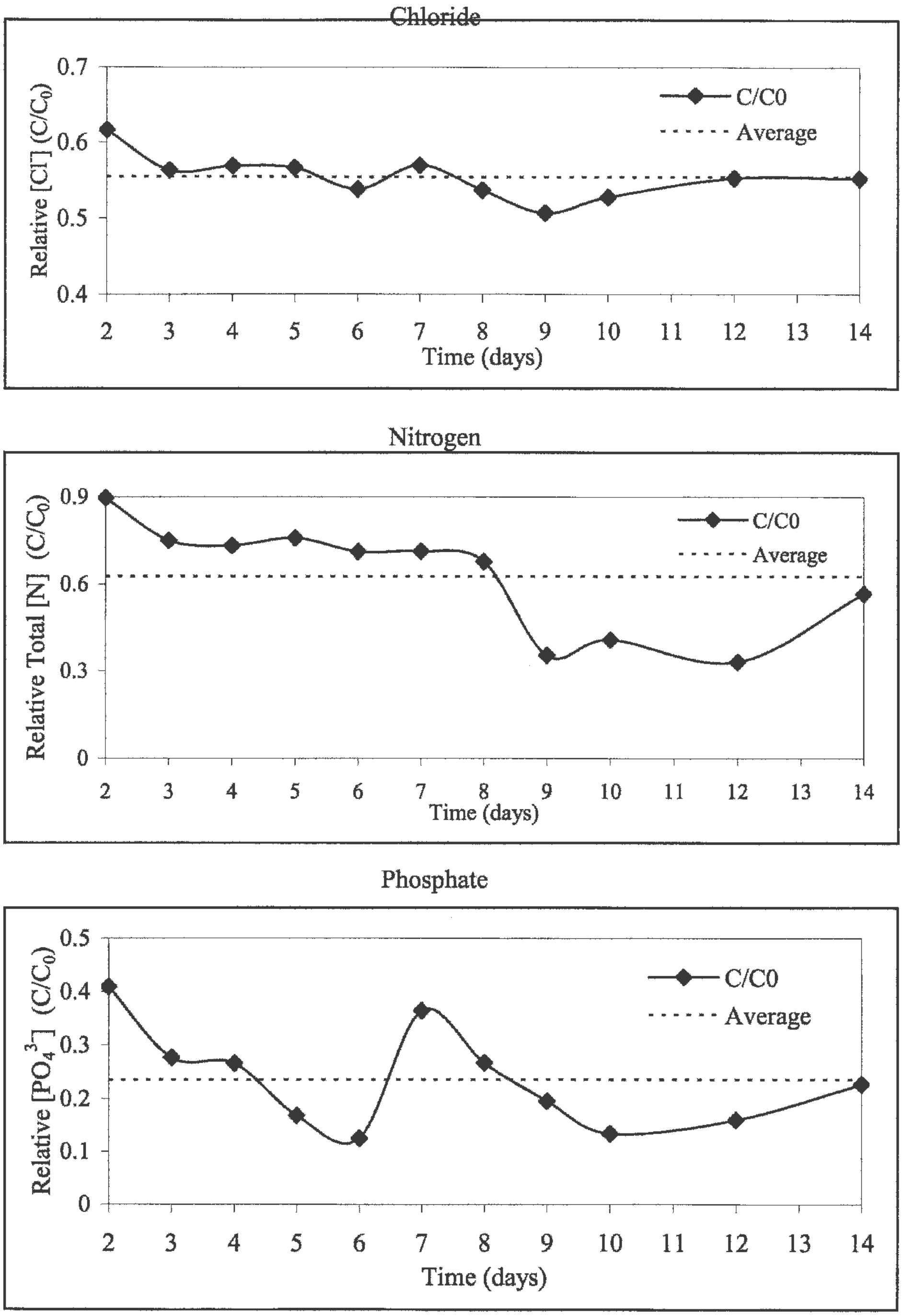

Figure 5. Breakthrough curves for relative concentrations of chloride, nitrate and phosphate.

This is attributed to the irrigator becoming stuck and the soil becoming saturated. The peak around day 7 for phosphorus is intriguing and the reasons for this are not entirely clear; it is possibly the result of some form of preferential flow.

Breakthrough curves are a useful tool for determining the percentage of leachate of nutrients passing through a soil. Even with a limited amount of time and money, the breakthrough curves have demonstrated at least in this case that a significant portion of the nutrients found in the Class A wastewater pass through the topsoil, hence representing a potential risk to groundwater reserves and water bodies connected to them. However, it should be noted that this case represents the worst-case scenario as nutrients may be absorbed by plants which is not considered in this experiment.

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