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DISPOSAL OF SECONDARY EFFLUENT FOR EUCALYPTUS IRRIGATION

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SUMMARY – The land application of sewage effluent and sludge is escalating in many parts of the world for irrigation and disposal purposes. We tested the hypothesis that reduced leaching and prolonged residence time in the soil profile will enhance the uptake of nutrients, the biodegradation of OM and the die-off of enteric bacteria introduced by effluent irrigation. A lysimeter simulation study was conducted where *Eucalyptus* trees were planted in tree soils and either fertigated or irrigated with oxidation ponds effluent (OPE). Irrigation was three times daily, every day. The trees were very resistant to increasing salinization of the soil solution, caused by low leaching fraction. Data from the 2nd year of the experiment is presented. Applied nitrogen was nearly completely intercepted in the soil-tree system, which was yet less efficient with respect to phosphorus (except in the more calcareous clay soil). Trace elements barely leached from the sludge-compost amended sand despite the heavy dosing (up to 625 kg/ha in the upper 20-cm layer). Salinity buildup in the soil solution elevated the SAR of the soil solution, and increased the ESP of the non-calcareous clayey soil. In addition, recalcitrant DOM accumulated in the soil solution. Hence, the simulation study showed that inasmuch as the trees withstood elevated salinity levels and the soil-plant effectively intercepted organic and inorganic pollutants, the long term quality of the soil was endangered.

Keywords: Biosolids, effluent irrigation, *Eucalyptus*, fecal coliforms, fertigation, leaching fraction, lysimeters, nitrogen, organic carbon, phosphorus, residence time, salinity, sodicity

1. INTRODUCTION

Sewage effluent is becoming the main, if not the only, source of water available for irrigation in semiarid regions of the world. However, effluents contain salinity components, organic and inorganic constituents, the concentrations of which depend on the quality and type of sewage and the degree of wastewater treatment (Feigin *et al*., 1991; Soffer *et al*., 1997). The rates of uptake and/or degradation of these constituents in the soil-plant system are often slower than their loading onto the soil. Thus, effluent-irrigated fields can become a source for organic and inorganic contaminants in soils and aquifers (Feigin *et al*., 1991; Amiel *et al*., 1990).

Irrigation with effluents, especially at lower degree of treatment, adds OC to the soil, part of which is DOC (Feigin *et al*., 1991). Effluent DOC can influence soil properties and behavior (e.g., soil redox potential, Patrick and Jugsujinda, 1992), and can interact with microcontaminants to enhance their transport in the soil, the unsaturated zone and the groundwater (e.g., Mingelgrin and Biggar, 1986; Gooddy *et al*., 1995; Han and Thompson, 1999). Siebe and Fischer (1996) found that irrigation with low-grade sewage effluent in the central Mexico valley greatly increased the contents of TOC and DOC in the upper soil layers and enhanced metal solubility and transport down the soil profile. The rate of migration of heavy metals was enhanced by the reductive dissolution of manganese oxides in the soil. Vulkan *et al*. (2000) showed that Dissolved Organic Matter (DOM) from unaerobically digested, waste-activated sludge increased the solubilities of Cu and Zn in sand columns.

Graber *et al*. (1995) showed that effluent irrigation substantially enhanced the transport of this organic micropollutant, which was applied to the field at agronomic rates. Seol and Lee (2000) suggested that slight but persistent suppression of sorption, together with alteration of other properties of the soil solution by effluent water components, could be important in pesticide mobilization in soils. In the study reported herein we used a lysimeter experimental design which utilized effluent irrigation vs. fertigation (tap water supplemented with nutrients) to simulate the response of a soil – plant system to restricted leaching regimes.

2. MATERIALS AND METHODS

Briefly, Two-hundred L drums were packed with dune sand or the A horizon of two clayey soils (a Calcic Haploxeroll and a Typic Palexeralf) and were either not-planted or planted with a Eucalyptus camaldulensis tree (for more detail see Fine *et al.*, 2002). In addition, some sand packed lysimeters were loaded with biosolids compost at rates equivalent to 125 and 625 Mg ha-1. Water and biosolids compositions are presented in Table 1. Irrigation was by surface drip, 3 times a day every day. Leaching fraction (LF; amount of water leached with respect to amount applied) from planted lysimeters was adjusted to ca. 20% or 5%. The latter was rather intermittent leaching regime. Leaching fraction from not-planted lysimeters was 90-100%. The leaching regimes provided residence times of the water in the soil that ranged from 0.8 d to some 40 days. Drainage water was sampled under confined atmosphere and in the event of microorganisms control, drainage was collected in an insulated icebox.

Table 1: Composition of the irrigation water

Component	Units	OPE	Fertigation	Biosolids
pH	-	7.76	7.4	
EC_{25}	dS m^{-1}	1.96	1,40	
OC	mg L^{-1}	192	7.84	210,000
BOD	Mg L^{-1}	134	-	
B	$\mu g\ L^{-1}$	590	150	25
Ba	$\mu g\ L^{-1}$	50	47.3	527
Ca	Mg L^{-1}	92	56	90,000
Cd	$\mu g\ L^{-1}$	0.3	0	6.4
Cu	$\mu g\ L^{-1}$	45	28	633
Fe	$\mu g\ L^{-1}$	454	248	14,440
K	Mg L^{-1}	41	28.5	3,184
Mg	Mg L^{-1}	36	30.5	8,447
Mn	$\mu g\ L^{-1}$	72	127	241
$N_{Kjeldhal}$	Mg L^{-1}	54	25.6 (as $N\text{-}NH_4$)	14,900
Na	Mg L^{-1}	270	119	2,700
Ni	$\mu g\ L^{-1}$	29.4	8.8	81
P	Mg L^{-1}	17	14	15,400
Pb	$\mu g\ L^{-1}$	5	<3	136
Zn	$\mu g\ L^{-1}$	166	260	2,468

Eucalyptus camaldulensis was chosen for the study because it is a fast growing tree which is resistant to both anaerobiosis and salinity. It is also common in ornamental and commercial planting in Israel.

3. RESULTS AND DISCUSSION

3.1 Tree growth and water uptake

Average fresh weight of the 2nd year canopy regrowth (following cutting at end of 1st year) ranged from 11 to 15.9 kg/tree. Peak daily water uptake amounted to 45 l/tree/d (Figure 1). Decreasing the leaching fraction from 20% to intermittent leaching in the beginning of August, increased the soil solution salinity level (not shown) and immediately reduced the water uptake by the trees.

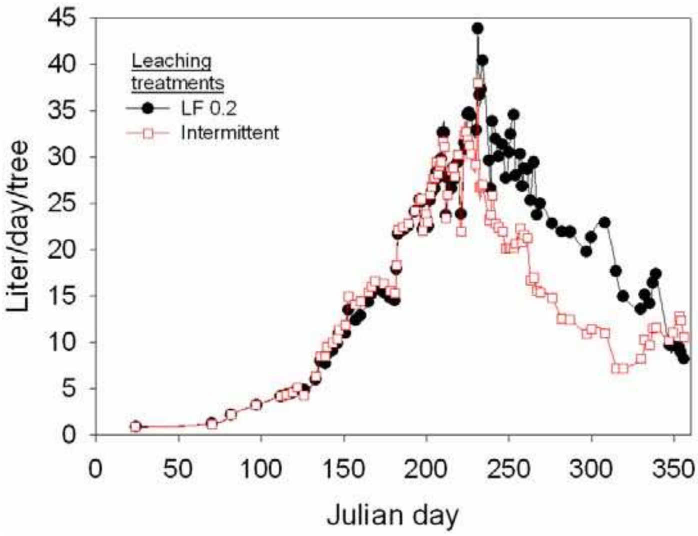

Figure 1. Average daily evapotranspiration of *Eucalyptus camaldulensis* trees grown in sand-packed lysimeters as affected by leaching treatment. Irrigation was 3 times daily every day. Results are shown from the 2nd year of the experiment. The data is from the 2nd year of the study.

3.2 Fate of applied nitrogen

The concentration nitrogen in the leachate (most all of which was nitrate) from the lysimeters was measured in 2-3 week intervals. These, and the amounts applied in the irrigation water, were used to calculate recoveries with respect to the entire irrigation season (see Fine *et al*., 2002 for details). Nitrogen recoveries in the leachate from fertigated lysimeters without a tree were circa 100% of the amounts applied (Figure 2)and the corresponding value in the effluent amended not-planted lysimeter was ca. 80%. Noteworthy is that the biosolids compost did not influence the recoveries; it was neither source nor sink for nitrogen. Note also that despite that the nitrogen was applied solely in reduced forms (ammonium and organic) (Table 1), virtually all of it appear in the leachate as nitrate. The difference in recoveries between effluent irrigation and fertigation was probably a consequence of physical filtration, and biological immobilization and denitrification. It is quite likely that under the conditions of the experiment; heavy and constant dosing of water and nitrogen, lack of a plant sink for the nitrogen, and partial reducing conditions in the lower 10-cm part of the soil profile, denitrification was the primary loss mechanism (Feigin *et al*., 1991).

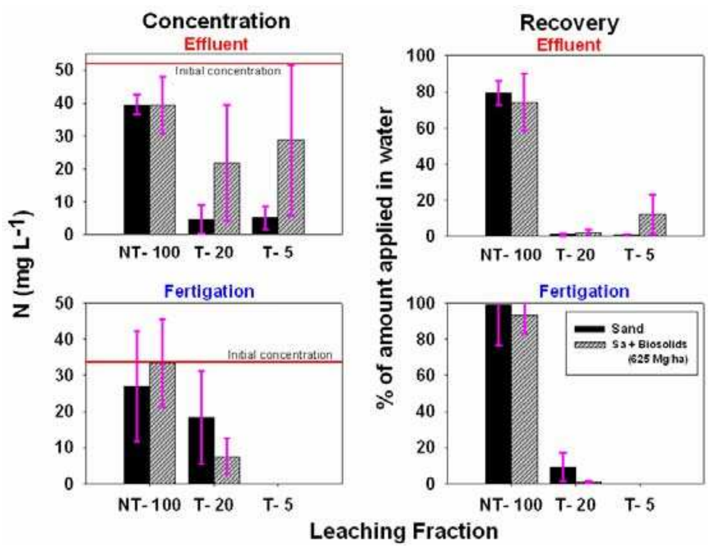

Figure 2: Nitrogen leaching from sand-packed lysimeters as affected by type of irrigation water, sludge compost addition, presence of a Eucalyptus camaldulensis tree and leaching regime. The

sludge compost was added at 625 Mg/ha to the upper 20-cm layer. Irrigation was 3 times daily every day. Results are shown from the 2nd year of the experiment. Overall water head at the end of the 2nd year was 3-6 m).

3.3 Effect of reduced leaching on soil solution salinity

Reduced leaching under the constant irrigation regime caused severe salination of the soil solution. This is shown in Figure 3 for all types of sand-packed lysimeters, namely with and without biosolids addition and at three leaching regimes (ca. 100%, 20% and intermittent). Under intermittent leaching, mean seasonal chloride concentrations reached 0.1 molarity. Leaching occurred due to reduced water uptake and to temporary decreases in the (Potential EvapoTranspiration) PET. Still irrigation continued and the salinity was diluted to some extent. Under deficit irrigation, soil solution salinity could be increased even further (data not shown). Without a tree present in the lysimeter, the chloride concentration in the leachate (and soil solution) was as in the irrigation water and all the amount that was applied was fully recovered in the leachate under irrigation with the two water types. The trees did cause retardation of chloride migration, which accounted to some 30-40% of the amounts applied. In part, this retardation was due to reduced transport rate in the soil profile, as was evident from the smaller recovery (and greater salinization) under the intermittent leaching regime compared with leaching at LF 0.2. In part, the retardation was due to uptake of chloride by the trees. It should be mentioned that chloride was only one anion to contribute to soil solution salinity, sulfate and bicarbonate were other dominant anions that enhanced soil solution salinization even further (data not shown). Note also that the biosolids compost had no effect on the salinization (at least this stage).

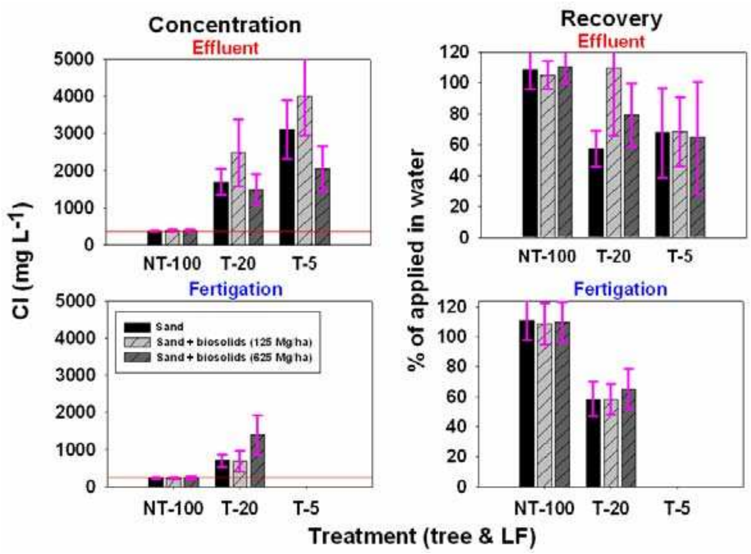

Figure 3: Chloride leaching from sand-packed lysimeters as affected by type of irrigation water, sludge compost addition, presence of a *Eucalyptus camaldulensis* tree and leaching regime. The sludge compost was added at 625 Mg/ha to the upper 20-cm layer. Irrigation was 3 times daily every day. Results are shown from the 2nd year of the experiment. Overall water head at the end of the 2nd year was 3-6 m.

3.4 Effect of reduced leaching on soil sodicity

The soil from the soil-packed lysimeters was sampled at 5-20 cm increments and extracted (at saturated paste moisture content) for SAR determination. The planted soil-packed lysimeters were irrigated at LF 0.2 (6 replicates) compared with not-planted lysimeters (2 replicates). The Sodium Adsorption Ratio (SAR) of the soil extracts (which correspond to soil Exchangeable Sodium Ratio (ESO); Richards, 1954) are presented in Figure 4 (the data points are placed at the midst of the interval depth). The calcareous and non-calcareous soils behaved very much differently in responding to effluent irrigation and even to fertigation under the two leaching regimes. The non-calcareous Palexeralf gained sodicity under reduced leaching regime (LF 0.2, with a tree in the lysimeter) and at a more severe level under the more saline/sodic type of irrigation water (Shainberg *et al*., 1980). Reduced leaching regime under fertigation did not increase the SAR of the calcareous soil but it did increase it under effluent irrigation below a depth of 20 cm. The increase in soil sodicity below this depth resulted probably from the increase of the salinity (and ionic strength) at this depth and the straight linear dependence of the SAR on salinity (Shainberg *et al*., 1980). With a tree in the lysimeter, the SAR at the top 5-cm soil layer was lower than without a tree. This can probably be related to elevated soil CO_2 concentrations, which emanated from soil and root respiration in this layer (data not shown). The CO_2 solubilized soil carbonates rendering Ca more soluble, thus negating sodicity buildup to some extent (Oster and Rhoades, 1990). This trend reversed at larger soil depth by increasing salinity and Ca complexation by carbonates and DOM.

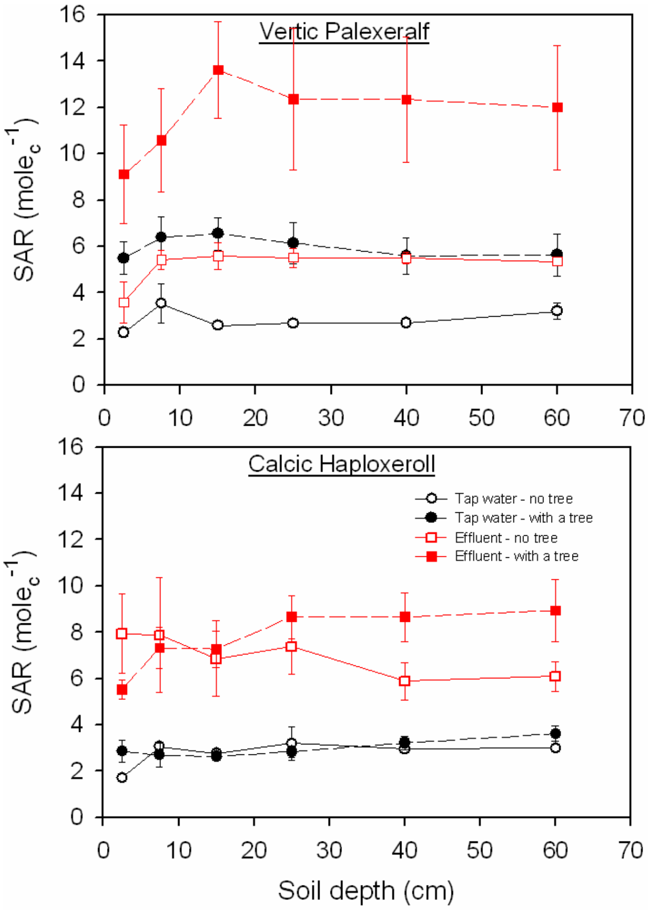

Figure 4: SAR of Terra Rossa (a Palexeralf) and Rendzina (a Haploxeroll) soils following 2-years fertigation or irrigation with OPE in lysimeters; with a *Eucalyptus camaldulensis* tree planted in the lysimeter or without. Irrigation was 3 times daily every day. Overall water head at the end of the 2nd year was 3-6 m. Leaching fraction was ca.100% without a tree and ≈20% with a tree.

3.5 Soluble organic carbon buildup in the soil profile under effluent irrigation

This issue was dealt with in detail by Fine *et al*. (2002). Briefly, a substantial proportion of the effluent OC was rather recalcitrant, and leached from the lysimeters even following 40 days residence and more. In as much as a most all (> 75%) of the OC added did degrade, the remaining fraction concentrated in the soil solution, yielding average concentrations of 150-250 mg C L^{-1}, respectively, under LF 0.2 and intermittent leaching regimes (Figure 5A). At the intermittent leaching regime in the sand-packed lysimeters (RT ≅ 20 d) the recovery of OC in the leachate was yet more than 15% of amount applied.

Note that inasmuch as the sizes of the root systems were large, their net OC contribution to the leachates was negligible. Furthermore, that low concentration of OC that was in the leachate from the sand-packed fertigated lysimeters (Figure 5B), can be attributed to the amount of EDTA that was in the irrigation water.

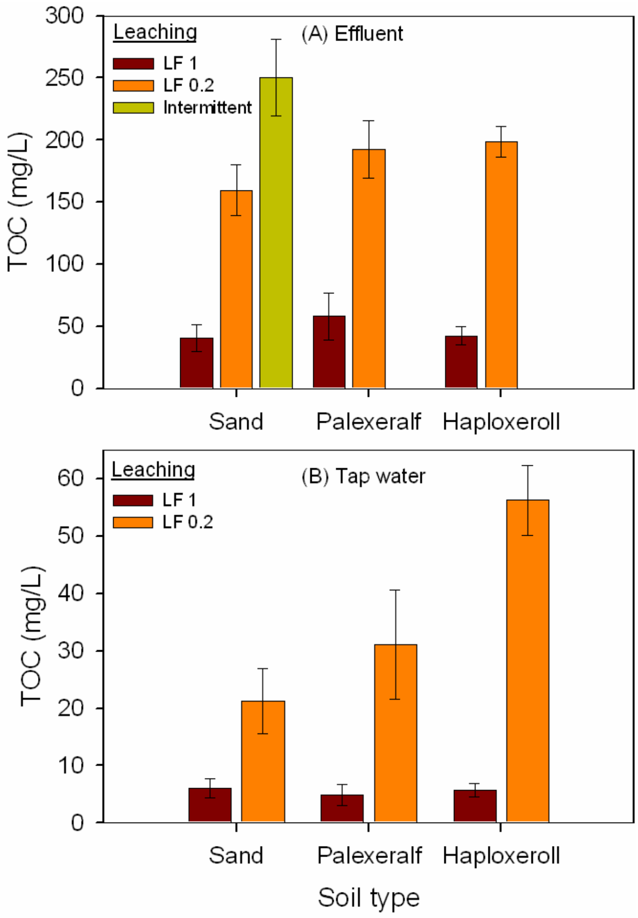

Figure 5: Average concentrations of organic carbon (OC) in leachate from lysimeters as affected by (i) type of irrigation water [(A) OPE vs. (B) fertigation], (ii) type of soil, and (iii) leaching fraction and presence of a *Eucalyptus camaldulensis* tree. Leaching fractions were ca. 100% (without a tree), 20% and intermittent leaching (average seasonal ≅5% leaching). The date presented is the averages (± standard errors) of periodic leaching events (every 2-4 weeks) during the irrigation season (April – November) of the 2^{nd} year of the experiment. Irrigation was 3 times daily every day. Overall water head at the end of the 2^{nd} year was 3-6 m.

3.6 Survival and leaching of indicator bacteria

We expected that at three times daily irrigations and short retardation in the 70-cm soil profile (LF 1; residence time (RT) in sand and soils < 0.8 - 2 days), leaching of indicator microorganisms (fecal coliforms; FC) will be rather undisturbed (Gerba *et al*., 1975; Frankenberger, 1985; Gantzer *et al*., 2001). However, this was not the case under the reduced leaching regime with a tree present in the lysimeter (LF 0.2; RT = 7-40 d, according to soil), in the sand and in the two clayey soils alike. Under these conditions, the average FC contents in the leachate has decreased only by 1-2 logs compared with the effluent water and the recoveries were 5-45% of the amounts applied (Figure 6). In fact, complete or near complete retardation/elimination (recoveries of 0-3%) of the FC's within the soil profile did occur under the free leaching regime. We refer this supposed discrepancy to relative rates of predation vs. re-growth which probably governed bacteria survival and ability to become transported. The balance between the two depended on the availability of biodegradable OC. Hence, while without a tree in the lysimeter, Biochemical Oxygen Demand (BOD) completely depleted down the soil profile, with a tree present, effluent-derived TOC concentrated, often to values yet higher that in the effluent itself (Figure 5), and substantial BOD's accompanied (data not shown). Hence, while without a tree predation dominated the fate of the FC's, with a tree present, OC derived from the effluent concentrated in the soil solution and together with root exudates, it supported FC's regrowth to an extent that allowed for their substantial survival and leaching.

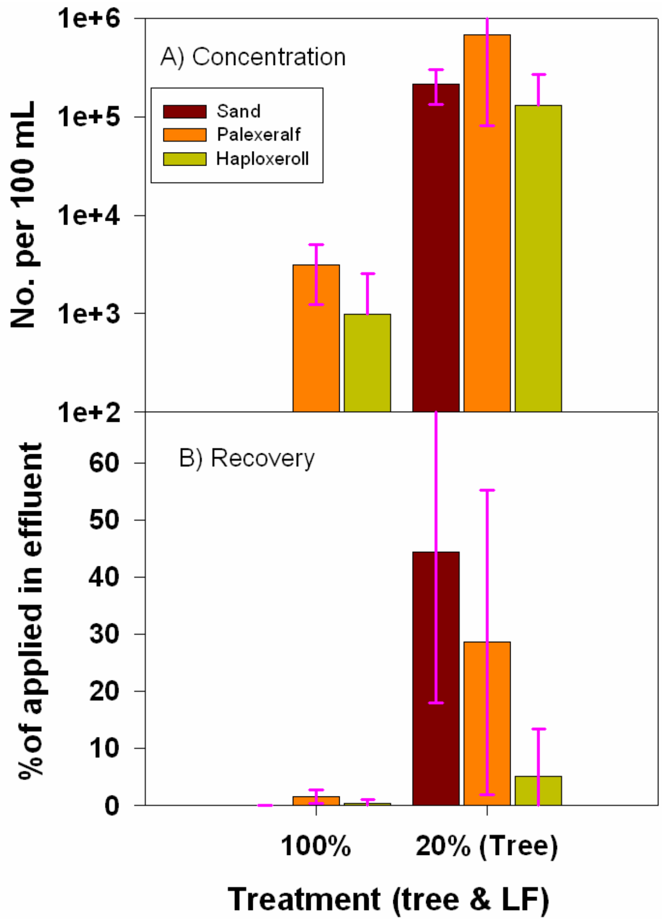

Figure 6: Leaching of fecal coliforms from OPE irrigated lysimeters as affected by (i) type of soil and (ii) presence of a *Eucalyptus camaldulensis* tree in the lysimeter and resultant leaching treatment. The date presented is averages and SE's of periodic sampling of leachate made every 2-4 weeks during the irrigation season (April – November) of the 2nd year of the experiment. The leachate was collected in ice boxes over a 6-12 hours period. Irrigation was 3 times daily every day. Overall water head at the end of the 2nd year was 3-6 m. Not planted lysimeters were in 2 replicates and planted were in 6 replicates. Leaching fractions were ca. 100% (without a tree) and 20% with a tree.

4. CONCLUSIONS

The present simulation study indicated that *Eucalyptus camaldulensis* plantations might be efficient interceptors of environmental contaminants applied to soils by effluent and biosolids. However, the combination of high effluent dosing and reduced leaching can promote undesired changes in the properties of the soil-plant system, thus limiting its long-term utilization and sustainability. Hence, under such circumstances, special care has to be taken with respect to soil salinity and sodicity, and to buildup of higher concentrations of recalcitrant DOM in the soil solution. These can potentially alter the behavior and fate of xenobiotic micropollutants as well as that of the soil constituents themselves.

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