MODIFICATIONS OF PHYSICAL AND CHEMICAL SOIL PROPERTIES BY APPLICATION OF TREATED PETROCHEMICAL EFFLUENT

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ABSTRACT

Wastewaters generated by Pólo Petroquímico do Sul (South Petrochemical Complex, Triunfo, Brazil) and treated up to tertiary level at SITEL (the integrated effluent treatment plant of the complex) are disposed of on land since 1983 at average rates of 140 m³/ha.day. With the purpose of studying the cumulative effect on soil properties of effluent applied under distinct conditions, four sites have been selected for comparison with adjacent blank areas. Soil samples have been taken for analyses from three different depths (0-30, 30-60 and 60-120 cm) and infiltration tests have been conducted on site.

Soil pH, electrical conductivity and extractable Na, Ca and S increased in treated areas, while exchangeable Al and extractable Zn decreased. Exchangeable K and Mg and extractable P, Cu, Mn and B, as well as other toxic metals, did not show significant modifications in comparison with blank areas, with the exception of cadmium. Infiltration rates showed an average fourfold decrease in soils which underwent effluent application, due to increase in pH and exchangeable Na and decrease in Al, all these factors contributing to clay dispersion.

The main alterations of forest and grassland environments consisted of trees falling caused by progressive weakening of the root system, due, in turn, to the change to a predominantly anaerobic soil environment and damage to some grass and shrub species, due to the direct impact of sprayed effluent. The observed results are compatible with the average effluent characteristics: low concentrations of toxic metals and negligible contents of residual organic toxicants, together with a high Sodium Adsorption Ratio.

With respect to the chemical status of the investigated soils the service life of the disposal system can be extended to decades, provided the discharges of Cd are restricted. As far as infiltration rates are concerned, the results are worrying, however. The soils can be reclaimed by fallowing of the application areas and/or addition of Ca and Mg in order to decrease the Exchangeable Sodium Percentage.

KEYWORDS
Petrochemical effluent; land treatment; effluent irrigation; soil chemistry; clay dispersion; infiltration rates; reclaiming of soils; cadmium contamination.
INTRODUCTION

Liquid effluent produced by the industries of the South Petrochemical Complex, an industrial district comprising one olefins plant and seven medium-sized second generation plants — without refinery — located in Triunfo, a small municipality near Porto Alegre, the capital city of the State of Rio Grande do Sul, Brazil, is pre-treated within the industries and conducted to SITEL/CORSAN. This is the integrated wastewater treatment system specially designed for providing full treatment in three stages for the segregated streams — organic and inorganic — discharged by the industries. The background on the implementation of SITEL and descriptions of the design criteria and start-up of the plant have been presented by Flores et al. (1983). After tertiary treatment in eight stabilization ponds the combined effluent is disposed of on land. Compliance with final effluent discharge standards is officially checked before disposal. A State Law prohibits discharge of any wastewater generated in the industrial area into surrounding waterbodies, including River Cai, one of the tributaries to the water supply sources for Porto Alegre. Since the term "wastewater" may apply even to, e.g., runoff from an overland flow system, the effluent must be totally dissipated by direct evaporation, infiltration into the soil and evapotranspiration. A slow-rate disposal system has therefore been designed on the basis of hydraulic balances only, not on removal efficiencies. Full details have been presented elsewhere (Simon et al., 1983).

The disposal areas are situated in the surroundings of SITEL. They are all covered by the original vegetation of the Complex region: eucalyptus woods intermingled with shrubby and grassy patches. The disposal system comprises two main subsystems using PVC perforated pipes and high capacity rotary sprinklers conveniently placed according to a thorough investigation on the ability of the local soils to accept artificial disposal of liquid (Klamt et al., 1982). Hydraulic application rates average 140 m³/ha.day or 9.8 cm/wk. A comparison between the two subsystems with respect to their performance and economics is presented elsewhere (Simon et al., 1986). After over two years of operation, apparently increased runoff and changes in the original vegetation became noticeable at certain spots of the disposal areas, bringing about the need for a better understanding of the interactions between the continuously applied waste and the physico-chemical properties of the soil.

METHODS AND PROCEDURES

Four representative sites were selected. For each site, two adjacent sampling points with the same soil type, slope and vegetation were examined, one of them being the blank. The characteristics of the sites are summarized in Table 1.

TABLE 1 - Characteristics of Sites Selected for Investigation in the Effluent Disposal Area of SITEL (1985)

<table>
<thead>
<tr>
<th>SITE NUMBER</th>
<th>LOCATION/SLOPE</th>
<th>VEGETATION</th>
<th>DISPOSAL SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Upper third of hill, 5% slope</td>
<td>Tall grasses, a few bushes</td>
<td>Perf. pipes</td>
</tr>
<tr>
<td>2</td>
<td>Lower third of same hill, 3% slope</td>
<td>Tall grasses, a few bushes</td>
<td>Perf. pipes</td>
</tr>
<tr>
<td>3</td>
<td>Top of small hill, 1% slope</td>
<td>Grasses only</td>
<td>Sprinklers</td>
</tr>
<tr>
<td>4</td>
<td>Flat, lower area</td>
<td>Eucalyptus</td>
<td>Perf. pipes</td>
</tr>
</tbody>
</table>

In February and March, 1985, field infiltration tests were performed according to the method of concentric rings (Forsythe, 1975), always from 5 to 7 days after interruption of effluent disposal. Soil aggregates were also determined.
Composite samples were taken from layers of three different depths: 0-30, 30-60 and 60-120 cm. Vegetation changes manifestly due to effluent application were qualitatively noted. Grass samples were also taken for identification of species.

The following parameters were determined in soil: pH of water extract; potential acidity by the SMP method (Shoemaker et al., 1961, modified as described by Mielniczuk et al., 1969); electrical conductivity of the 1:5 water extract; Al, Ca, Mg and Mn extracted by 1N KCl solution; P, K and Na extracted by 0.05N HCl + 0.025N H2SO4; B extracted by warm water; Fe extracted by ammonium oxalate; water soluble Cl−; Zn, Cu, Ni, Cr, Cd, Pb and Hg extracted by 0.1N HCl; organic carbon by wet oxidation and total N by the Kjeldahl method; physical analysis according to Bouyoucos (1951). The methodology has been adapted and described by Tedesco et al. (1985).

The raw numerical results were t-tested; the four sites were taken as replicates. Average effluent characteristics monitored by SITEI from 1984 to 1985 were also compiled and compared with available data on the quality of River Caǐ. File searches were also necessary to correctly estimate the total volumes of effluent applied to the different sites from the very beginning of the operation of the system.

RESULTS AND DISCUSSION

Table 2 shows the data on final effluent and water of River Caǐ. Discharge standards set by the Department of Environment of the State are also shown; these are averages calculated over different periods according to the required sampling frequencies. With regard to the effluent, Total Suspended Solids and BOD are low; pH varies from neutral to 9.8; chloride, sulfate and sodium are high (the effluent is known to be contaminated with sodium chloride and sodium sulfate from catalysts and neutralization processes used by the industries). The effluent quality is better than the river water quality for many control parameters, including some metals. The higher concentrations of chromium in the river water may be due to discharges of wastes from tanneries upstream of the sampling point. The Sodium Adsorption Ratio calculated for the effluent amounts to the disturbing value of 44.9 — higher than representative values published for several other types of effluent (Overcash and Pal, 1981).

Chemical analyses (Table 3)

pH, potential acidity and exchangeable aluminum. The alkaline pH values of the effluent produced an increase in pH of topsoil from 4.9 to 5.8; similar effects were also observed in deeper layers. The consequences were decreases in potential acidity (indicated by the SMP index) and in exchangeable Al. This is beneficial to the environment, since the capacity of fixation of metals by the soil probably increased too (Walsh et al., 1976; Roesh, 1979; Martins, 1984).

Electrical conductivity, exchangeable sodium, chlorides and CEC. The manifestly appreciable concentrations of ions sodium and chloride in the effluent (Table 3) certainly caused significant increases of the concentrations of both ions in the soil profile, increasing the electrical conductivity particularly in the topsoil. The values are typical of normal, low salinity soils (Overcash and Pal, 1981). Due to their high solubility in water, Na and Cl in soil are strongly affected by their concentrations in the effluent together with dilution by rainwater. Other factors, e.g. hydraulic conductivity and CEC of soil are also important. In any case, these ions will ultimately reach the river through groundwater. However, due to the peculiar lay-out of the South Petrochemical Complex, this effect will take place upstream of the point of raw water abstraction for industrial use in the Complex. If the contamination by Na and Cl eventually becomes significant, the industry will be the first to be affected. The increase in Na content of the soil, combined with high pH and low concentrations of divalent ions, can expressively contribute to soil dispersion and consequent reduction of infiltration capacity (Richards, 1969). This indeed occurred in soils of SITEI. In order to calculate the Cation Exchange Capacity (CEC) via sum of cations and hence the Exchangeable Sodium Percentage (ESP),
TABLE 2 - Average Characteristics of Final Effluent Discharged by SITE and Water of River CAI in Comparison with Final Effluent Discharge Standards (January, 1984 to October, 1985).

<table>
<thead>
<tr>
<th>Parameter (1)</th>
<th>Conc. in Final Effluent (2)</th>
<th>Conc. in River CAI(3)</th>
<th>Discharge Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.4 (18)</td>
<td>7.1 (9)</td>
<td>6 - 9</td>
</tr>
<tr>
<td>Temperature, °C</td>
<td>22.2 (18)</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Total Susp. Solids, ppm</td>
<td>22.8 (18)</td>
<td>53.4 (10)</td>
<td>40</td>
</tr>
<tr>
<td>Total Diss. Solids, ppm</td>
<td>513.2 (18)</td>
<td>58.2 (10)</td>
<td>2000</td>
</tr>
<tr>
<td>BOD₅, ppm</td>
<td>4.4 (18)</td>
<td>1.4 (10)</td>
<td>15</td>
</tr>
<tr>
<td>COD, ppm</td>
<td>43.6 (18)</td>
<td>41.6 (10)</td>
<td>100</td>
</tr>
<tr>
<td>TOC, ppm</td>
<td>22.0 (18)</td>
<td>6.0 (6)</td>
<td>50</td>
</tr>
<tr>
<td>Oil and grease, ppm</td>
<td>7.7 (18)</td>
<td>8.2 (10)</td>
<td>10</td>
</tr>
<tr>
<td>Phenols, ppb</td>
<td>7 (17)</td>
<td>113 (8)</td>
<td>50</td>
</tr>
<tr>
<td>Surfactants, ppb</td>
<td>30 (13)</td>
<td>2 (7)</td>
<td>1000</td>
</tr>
<tr>
<td>Chloride, ppm</td>
<td>121.9 (18)</td>
<td>5.7 (10)</td>
<td>700</td>
</tr>
<tr>
<td>Ammonia, ppm</td>
<td>.32 (18)</td>
<td>.34 (10)</td>
<td>-</td>
</tr>
<tr>
<td>Nitrate, ppm</td>
<td>.59 (14)</td>
<td>.61 (10)</td>
<td>-</td>
</tr>
<tr>
<td>Nitrite, ppm</td>
<td>.02 (18)</td>
<td>.01 (9)</td>
<td>-</td>
</tr>
<tr>
<td>N (total), ppm</td>
<td>1.22 (16)</td>
<td>.71 (10)</td>
<td>10</td>
</tr>
<tr>
<td>P (total), ppm</td>
<td>.10 (17)</td>
<td>.13 (10)</td>
<td>.5</td>
</tr>
<tr>
<td>Sulfate, ppm</td>
<td>211.2 (15)</td>
<td>15.5 (6)</td>
<td>-</td>
</tr>
<tr>
<td>Sulfide, ppb</td>
<td>37 (16)</td>
<td>20 (10)</td>
<td>200</td>
</tr>
<tr>
<td>Sodium, ppm</td>
<td>176 (4)</td>
<td>17.5 (4)</td>
<td>-</td>
</tr>
<tr>
<td>Potassium, ppm</td>
<td>5.5 (4)</td>
<td>1.8 (4)</td>
<td>-</td>
</tr>
<tr>
<td>Calcium, ppm</td>
<td>27.5 (4)</td>
<td>4.8 (4)</td>
<td>-</td>
</tr>
<tr>
<td>Magnesium, ppm</td>
<td>3.25 (12)</td>
<td>2.5 (10)</td>
<td>-</td>
</tr>
<tr>
<td>Copper, ppb</td>
<td>14 (8)</td>
<td>8 (10)</td>
<td>500</td>
</tr>
<tr>
<td>Zinc, ppb</td>
<td>209 (14)</td>
<td>68 (10)</td>
<td>1000</td>
</tr>
<tr>
<td>Lead, ppb</td>
<td>54 (5)</td>
<td>19 (10)</td>
<td>100</td>
</tr>
<tr>
<td>Cadmium, ppb</td>
<td>4.7 (5)</td>
<td>BDL (10)</td>
<td>100</td>
</tr>
<tr>
<td>Mercury, ppb</td>
<td>.1 (4)</td>
<td>BDL (10)</td>
<td>.2</td>
</tr>
<tr>
<td>Nickel, ppb</td>
<td>34 (8)</td>
<td>6 (10)</td>
<td>-</td>
</tr>
<tr>
<td>Titanium, ppb</td>
<td>9.4 (5)</td>
<td>BDL (9)</td>
<td>5000</td>
</tr>
<tr>
<td>Chromium (VI), ppb</td>
<td>.2 (4)</td>
<td>BDL (7)</td>
<td>50</td>
</tr>
<tr>
<td>Chromium (total), ppb</td>
<td>14.6 (5)</td>
<td>112 (10)</td>
<td>400</td>
</tr>
<tr>
<td>Aluminum, ppm</td>
<td>1.94 (16)</td>
<td>2.74 (10)</td>
<td>5</td>
</tr>
<tr>
<td>Iron, ppm</td>
<td>1.50 (16)</td>
<td>3.59 (10)</td>
<td>5</td>
</tr>
<tr>
<td>Manganese, ppm</td>
<td>.07 (16)</td>
<td>.12 (10)</td>
<td>.5</td>
</tr>
<tr>
<td>Cyanide, ppb</td>
<td>1.3 (18)</td>
<td>1.2 (10)</td>
<td>50</td>
</tr>
</tbody>
</table>

(2), (3) Parameters monitored at different frequencies. Values are averages of monthly averages. Number of monthly averages taken into account are between brackets. BDL = Below Detection Limit for the analytical method employed.

Concentrations of hydrogen ion were worked out from the following relationship established for soils of Rio Grande do Sul (Bissani, 1985):

\[ 1 + \log Y = 3.80 - 0.426 X, \]

where

\[ Y = \text{Sum of concentrations of H and Al extracted by } 1N \text{ solution of Ca acetate in pH=7, expressed in me/dl;} \]

\[ X = \text{SMP Index.} \]

The results in Table 3 show low values of CEC being slightly affected by the rise in soil pH of the treated soils, particularly in the deepest layer, where soil pH increased by 0.8 with a respective CEC increase of 15% - comparable with the 30% increase cited by Overcash and Pal (1981) for an increase in soil pH from 5 to 7. The availability of ions for uptake by plants decreases with increasing CEC (Haghiri, 1974; Miller, 1976; Martins, 1984), which can prove...
Modification of physical and chemical soil properties

TABLE 3 - Results of Chemical Analyses - Averages of Four Sites

<table>
<thead>
<tr>
<th>Parameter (1)</th>
<th>0-30</th>
<th>30-60</th>
<th>60-120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elect. Conductivity, mS/cm</td>
<td>0.101</td>
<td>0.046</td>
<td>0.089</td>
</tr>
<tr>
<td>pH in Water</td>
<td>5.8</td>
<td>4.9</td>
<td>5.7</td>
</tr>
<tr>
<td>SMP Index</td>
<td>6.7</td>
<td>6.1</td>
<td>6.5</td>
</tr>
<tr>
<td>Na - exchangeable, ppm</td>
<td>172</td>
<td>11</td>
<td>199</td>
</tr>
<tr>
<td>K - exchangeable, ppm</td>
<td>34</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>Al - exchangeable, me/dl</td>
<td>1</td>
<td>1.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Ca - exchangeable, me/dl</td>
<td>2.0</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Mg - exchangeable, me/dl</td>
<td>2.6</td>
<td>1.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Mn - exchangeable, ppm</td>
<td>4.5</td>
<td>4.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Cation Exch.Capacity, me/dl (2)</td>
<td>0.55</td>
<td>0.66</td>
<td>0.841</td>
</tr>
<tr>
<td>Exchang.Sodium Percent., %</td>
<td>16.4</td>
<td>1.13</td>
<td>21.1</td>
</tr>
<tr>
<td>P - available, ppm</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Organic Matter, %</td>
<td>1.4</td>
<td>1.7</td>
<td>1.0</td>
</tr>
<tr>
<td>S - extractable, ppm</td>
<td>6.3</td>
<td>3.2</td>
<td>7.9</td>
</tr>
<tr>
<td>Cu - extractable, ppm</td>
<td>1.2</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Zn - extractable, ppm</td>
<td>5.5</td>
<td>7.3</td>
<td>4.0</td>
</tr>
<tr>
<td>B - extractable, ppm</td>
<td>0.5</td>
<td>0.46</td>
<td>0.37</td>
</tr>
<tr>
<td>N - total, %</td>
<td>0.055</td>
<td>0.066</td>
<td>0.104</td>
</tr>
<tr>
<td>Chloride, ppm</td>
<td>62</td>
<td>27</td>
<td>71</td>
</tr>
<tr>
<td>Fe - extractable, %</td>
<td>0.09</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>Cd - extractable, ppb</td>
<td>54.2</td>
<td>4.8</td>
<td>67.1</td>
</tr>
<tr>
<td>Pb - extractable, ppb</td>
<td>1.38</td>
<td>1.88</td>
<td>1.78</td>
</tr>
<tr>
<td>Ni - extractable, ppm</td>
<td>0.53</td>
<td>0.41</td>
<td>0.40</td>
</tr>
<tr>
<td>Cr - extractable, ppm</td>
<td>0.36</td>
<td>0.19</td>
<td>0.12</td>
</tr>
<tr>
<td>Hg - extractable, ppb</td>
<td>BDL</td>
<td>BDL</td>
<td>BDL</td>
</tr>
</tbody>
</table>

(1) Methods according to Tedesco et al. (1985).
(2) Calculated by summing concentrations of cations Na, K, Ca, Mg, Mn and (H+Al) in me/dl.
* Denotes statistically significant difference at P = 0.05 by the t-test applied in the comparison between effluent application points with blanks at the same depths.

BDL = Below Detection Limit for the analytical method employed.

either beneficial or detrimental, depending on the compartment of the environment to be preferentially protected. The favorable situation for SITEL would be predominant fixation by plants — particularly trees — since no present or future use is intended for them. The increase in Exchangeable Sodium Percentage (ESP) in all layers strongly points to the effects on the infiltration rates observed. According to the graph presented by Martin et al. (1964), the hydraulic conductivity of topsoil would experience a sevenfold decrease, which is not very different from the average effect actually measured.

Potassium, calcium and magnesium. Concentrations of these metals in the effluent are low, as well as the exchangeable concentrations of their ions in the soil. This, together with the high concentrations of Na, militates against the physical stability of the soil, since the effluent has a high SAR and does not have the chemical characteristics capable of reducing the clay dispersion effects in soil.

Sulfur, phosphorus, chloride, boron and organic matter. Due to the high concentration of sulfate in the effluent, extractable sulfur in soil under effluent application increased from 3.2 to 6.3 ppm on average (surface layer).
This level is still considered low for sulfur-demanding annual crops (Tedesco et al., 1985). Extractable sulfur increased also in deeper layers.

Chloride in soil underwent similar variations. The concentration of this ion increased from 27 to 62 ppm in the surface layer of soil subject to effluent disposal. The effect was the same throughout the soil profile due to the high mobility of Cl.

Phosphorus, boron and organic matter did not change significantly due to effluent application. Coherently, the effluent is not particularly rich in these constituents. While the content of boron in the soil is considered adequate, phosphorus is very low for annual crops. The low content of organic matter was not much affected by the organic load of the effluent, which is also very low (Table 2) and may undergo further biodegradation and erosion by rainwater after disposal.

Zinc, copper, manganese and iron. The average zinc content of the soil decreased from 7.3 to 5.5 ppm in the surface layer under effluent application, which is probably due to the increase in pH and the consequent immobilization of ions. Application of effluent did not affect extracted copper, manganese or iron in the soil; the concentrations of these constituents in the effluent are not significant.

Cadmium, nickel, lead, chromium and mercury. In spite of the low average concentration of cadmium in the effluent, extractable cadmium increased several fold in the upper 60 cm of soil. Individual results (not shown in Table 3) showed high Cd concentrations in only two of the sites investigated, indicating occasional, localized loadings of this metal. Even though naturally occurring Cd in soils can reach concentrations as high as 700 ppb (Lindsay, 1979), artificial introduction of the metal into soils should be kept at a minimum due to the ease of its translocation to the plant tops (Martins, 1984). Similar to what happens with other toxic metals, total applied loads of Cd restrict the service life of disposal areas. In the case of SITEL — where the excess activated sludge is also applied on land — the recommended cumulative loading is 10 kg/ha for the sludge farming areas (Nolan, 1982). More flexible criteria have been recommended, e.g., 2.24 kg Cd/ha.year for a service life of 10 years (Aserhoff et al., 1970), as well as more restrictive criteria, e.g. 0.5 kg Cd/ha.year for "accumulator" crops (U.S.E.P.A., 1979) and 5 kg/ha (total) for uncontaminated non-calcareous land over a 30 year period (DoE, 1984). In SITEL the highest effluent loadings were applied on the 50-ha sprinkler subsystem: 125,523 m3/ha over 32 months of operation. Taking into account the average Cd concentration in the effluent (Table 2), the respective service life of this subsystem would be of 22.6 years under restrictive criteria.

Extracted mercury, chromium, lead and nickel did not change significantly in soils under effluent application; their concentrations were very low or below detection limit in all samples.

Physical analyses (Table 4)

Particle size and soil dispersion. Soils of the four sites studied vary from loamy sand to sandy clay loam in the upper layer, without prominent clay horizons in the surface or subsurface layers. With the exception of Site 4, where a water table near the surface was observed, they presented good internal drainage. The reduction of mean size of aggregates is evident; this demonstrates the soil dispersion caused by continuous application of a liquid bearing the characteristics already stressed.

Water infiltration rate. The application of effluent brought about sharp reductions of final (steady) infiltration rates. However, the average decrease from 26.5 to 6.57 cm/h does not correctly reflect the drastic effects observed in certain sites. These are clear in Table 5, where individual results for all sites are shown. As seen in this Table, no relationship can be established between the total volume of effluent applied per hectare of the sub-zone in which a given sampling site is situated and the acuteness of the effect.
### TABLE 4 - Results of Physical Tests - Averages of Four Sites

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Depth (cm)</th>
<th>0-30</th>
<th>30-60</th>
<th>60-120</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated</td>
<td>Blank</td>
<td>Treated</td>
<td>Blank</td>
</tr>
<tr>
<td><strong>PARTICLE SIZE WITH ALKALI DISPERSION:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Sand, %</td>
<td>26</td>
<td>24</td>
<td>27</td>
<td>23</td>
</tr>
<tr>
<td>Fine Sand, %</td>
<td>55</td>
<td>51</td>
<td>53</td>
<td>52</td>
</tr>
<tr>
<td>Silt, %</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Total Clay, %</td>
<td>17</td>
<td>24</td>
<td>16</td>
<td>23</td>
</tr>
<tr>
<td><strong>PARTICLE SIZE WITH WATER DISPERSION:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse Sand, %</td>
<td>30</td>
<td>24</td>
<td>27</td>
<td>24</td>
</tr>
<tr>
<td>Fine Sand, %</td>
<td>62</td>
<td>63</td>
<td>62</td>
<td>69</td>
</tr>
<tr>
<td>Silt, %</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Natural Clay, %</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td><strong>SOIL FLOCCULATION, %</strong></td>
<td>70</td>
<td>75</td>
<td>62</td>
<td>82</td>
</tr>
<tr>
<td><strong>WATER CONTENT, %</strong></td>
<td>15.5*</td>
<td>10.3</td>
<td>15.9</td>
<td>9.8</td>
</tr>
<tr>
<td><strong>STEADY INFILTRATION RATE, cm/h</strong></td>
<td>6.57*</td>
<td>26.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>TWO HOURS TOTAL INFILTRATION, cm</strong></td>
<td>15.8*</td>
<td>62.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>AGGREGATES WEIGHTED MEAN DIAMETER, cm</strong></td>
<td>2.71*</td>
<td>5.40</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Denotes statistically significant difference at P = 0.05 by the t-test applied in the comparison between effluent application points with blanks at the same depths.

### TABLE 5 - Individual Results of Steady Infiltration Rates for the Four Sites Investigated and Total Volumes of Effluent Applied.

<table>
<thead>
<tr>
<th>SITE NUMBER</th>
<th>STEADY INFILTRATION RATE, cm/h</th>
<th>VOLUMES OF EFFLUENT APPLIED ON THE SUB-ZONE TO WHICH EACH SITE BELONGS, m³</th>
<th>PERIOD OF APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Treated</td>
<td>Blank</td>
<td>TOTAL</td>
</tr>
<tr>
<td>1</td>
<td>4.6</td>
<td>17.1</td>
<td>4,267,779</td>
</tr>
<tr>
<td>2</td>
<td>18.5</td>
<td>58.1</td>
<td>4,267,779</td>
</tr>
<tr>
<td>3</td>
<td>2.5</td>
<td>17.1</td>
<td>5,781,304</td>
</tr>
<tr>
<td>4</td>
<td>.7</td>
<td>13.7</td>
<td>1,544,712</td>
</tr>
</tbody>
</table>

measured for the same site. For example, the maximum and minimum reductions of infiltration rates, namely, by factors of 19.6 (Site 4) and 3.1 (Site 2) were detected in sub-zones submitted to similar loadings of effluent. Coincidentally, the maximum reduction took place in the site submitted to the lowest loading of effluent - which presents, however, the least adequate topography for effluent application. In fact, Site 4 is flat and offers little conditions for the liquid to rapidly move away from the disposal points, both via local runoff and via lateral flow of soil water. Although more intensive sampling might have led to smoother data, it is evident that the "threshold loading" of effluent for application on this particular soil with respect to dispersion effects is
probably much below 96,000 m³/ha. Since results of tests made with flooding-
type, concentric rings infiltrometers can differ from results obtained by using
other types of instruments and covers by as much as eight times (Musgrave and
Holtan, 1964), the present average infiltration rate of application areas
around SITEL could be estimated, for the sake of safety, at 0.82 cm/h. This
corresponds to 82% of the design rate (Simon et al., 1983 and 1986). This will
bring about an unexpected reduction of the design-service life of the disposal
area, unless reclamation measures are taken. The following measures are now
under detailed consideration by SITEL and the Health and Environment Department
of the State:

- Fallowing of the application areas in parallel with seasonal utilization of
  contiguous areas, e.g., by cultivation of rice irrigated with effluent on the
  floodplain of River Cañ during the summer;
- Application of Ca in order to counterbalance the dispersing effect of Na;
- Enrichment of the vegetation by artificially introducing species more adapted
to wet and/or swampy environments;
- Ploughing of the upper layer of soil in order to expose the deeper material
to effluent, falling leaves, etc., burying the rotting green mass and
increasing the roughness of the surface;
- Improvement of distribution of runoff over the areas surrounding the
  application sites by opening small ditches and furrows, building small dikes
and mud walls, etc.

Modifications of vegetation

The predominantly saturated soil profile affected the root system of the
eucalyptus originally grown on well aerated soils, causing falling of trees
particularly in the higher zones. Growth of new trees, however, did not cease.
Some species typical of wet environments slowly developed on the application
points and their surroundings, thus precluding severe erosion and
desertification. Tall grasses were less affected than trees. On spots subject
to direct impact of liquid discharged by sprinklers, however, several species
of shrubs and grasses were extinguished; only Cynodon dactilon (bermuda grass)
and Paspalum urvillei showed good adaptation to this unfavorable condition. As
an overall qualitative assessment of the impact of the effluent on the original
vegetation of the application zones, it can be said that no significant
detrimental effect has been produced to date.

CONCLUSIONS

Effluent application increased pH values and concentrations of sodium, chloride
and sulfate in the topsoil (with observable effects also in the deeper layers),
in strict correlation with the nature of the inorganic dissolved solids of the
effluent. The potential acidity decreased. Organic matter, other plant
nutrients and heavy metals showed negligible alterations, except for cadmium;
the concentration of this metal in all layers of two of the four sites showed
a sharp increase. Soil dispersion was observed in all sites. Effluent
infiltration rates showed a fourfold decrease of the average steady value; this
effect bore some relationship to the predictions of alterations of soil
hydraulic conductivity worked out from the Exchangeable Sodium Percentages.
Some dramatic individual results of infiltration tests can be looked at as a
warning for designers of other disposal systems in the case of similarities
between the soils/effluents of SITEL and soils/effluents concerned. The
situation is not irreversible, however; some measures — certain of which are
common agricultural practice — can be easily taken. Major detrimental effects
on the vegetation were not observed.
ACKNOWLEDGEMENTS

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REFERENCES


