THE SEALING OF SOILS BY MANURE.
II. SEALING MECHANISMS

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The sealing mechanisms for soils being infiltrated by dairy and swine slurries were investigated using laboratory infiltration columns. Physical mechanisms were found to be predominant especially for dairy slurries. Biological mechanisms intervene to strengthen physical seals only where ambient temperatures exceed 15°C. Biological mechanisms are especially important in the sealing of soils by swine slurries as their physical mechanisms are weaker than those of dairy slurries. Chemical mechanisms were found to be insignificant.

INTRODUCTION

A preliminary project (Barrington et al. 1987) established that physical mechanisms play a primary role in the sealing of soils by manure. Furthermore, dairy manures of 6% and 10% total solids (TS) were successful in sealing soils to infiltration rates below 8.64 x 10^-4 m/d (10^-6 cm/s), even on soils with initial permeability values exceeding the limits set by the Ontario and Quebec environmental authorities.

These findings were in agreement with those of several previous research works. DeTar (1977, 1979) demonstrated, using manure seeping through silty soils, that TS content above 1.8% was far more significant in controlling final infiltration rates than either soil saturated hydraulic conductivity to water (k) or manure hydraulic head. Lo (1977) found, using dairy lagoon liquids over columns of various soil textures, that final infiltration rates were not significantly different despite wide variations in hydraulic heads. Rowsell (1980) compared sealing effects of screened beef manure, formaldehyde-sterilized screened beef manure and two salt solutions on various soil textures. He concluded (1) that the sealing seemed to reside within the organic mat which accumulated at the soil surface, (2) that biological sealing mechanisms were insignificant and (3) that chemical mechanisms resulted perhaps from the soil destructuring effect of the manure's neutral pH.

Miller et al. (1976) sampled four earthen manure reservoirs, two in use for 2 yr and two others in use for 8 yr. Their sampling indicated significant contaminant accumulation as deep as 150 cm below the reservoir-soil interface. Sampling only four reservoirs, Miller could not establish a correlation between soil clay content or reservoir age and the quantities of nutrients accumulated within the reservoir profiles. Miller and Robinson (1981) also monitored groundwater quality below a beef manure earthen reservoir to observe the presence of nitrate and chloride seepages. Barrington et al. (1987) report several other authors having monitored groundwater quality around earthen manure storages. Some of the authors observed seepage effects but not under a systematic basis.

This project, following from that of Barrington et al. (1987), aims at investigating the specific mode of action as well as the relative importance of the physical, biological and chemical sealing mechanisms.

PROCEDURE

The investigation of the three sealing mechanisms was carried out through four laboratory infiltration trials. Except for the chemical mechanism investigation, all assays were performed using plexiglas tubing of 0.14 m inside diameter. A coarse sand column, 0.15 m high, was placed at the lower extremity of the tubing and was subjected to various constant manure hydraulic heads (Fig. 1). Both dairy and swine slurries were used for these trials, the former containing 9% total solids (TS) and latter 6% TS. The particle size analysis for the coarse sand is presented in Table 1.

The first trial compared sealing efficiency between physical and biological mechanisms. Using the setup described in Fig. 1, formaldehyde-sterilized slurries (Rowsell 1980) and natural slurries were tested for infiltration rate over coarse sand columns 0.14 m in diameter by 0.15 m in height. The coarse sand was assumed to demonstrate minimal chemical activity. Slurry hydraulic head as well as total solids content were maintained constant by returning to the individual column, the liquids collected as seepages (exfiltrates).

The second trial pertained to the sealing effects of chemical mechanisms. Eight clay soil samples, 0.048 m in diameter by 0.010 m high, were compacted at the bottom of aluminum tubes (Fig. 2). After measuring the saturated hydraulic conductivity of each clay core, four columns were soaked in tap water and four more columns were soaked in swine slurry. All eight columns were kept under temperatures of 0-5°C for minimum bacterial activity. Care was taken as to soak the clay samples from the bottom of the tubes to prevent any manure solids from infiltrating from the surface and thus creating a physical seal. The saturated hydraulic conductivity of each column was measured initially as well as after 1 wk and 2 wk of soaking. These permeability measurements require the infiltration of a volume of water, representing four times that of the soil cores. Thus, the cores’ permeability to water was expected to change between trials and soaking periods. Nevertheless, chemical sealing effects should produce an additional change in permeability among core groups, if significant. Analysis of variance was used as statistical method to compare the effects of the two treatments, water and swine slurry soaking.

Table 1. Particle size analysis of coarse sand utilized in infiltration columns

<table>
<thead>
<tr>
<th>Particle size (μm)</th>
<th>Fraction (%)</th>
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<tbody>
<tr>
<td>&lt;2</td>
<td>Trace</td>
</tr>
<tr>
<td>53-2</td>
<td>Trace</td>
</tr>
<tr>
<td>53-75</td>
<td>1</td>
</tr>
<tr>
<td>75-150</td>
<td>9</td>
</tr>
<tr>
<td>150-250</td>
<td>82</td>
</tr>
<tr>
<td>&gt;250</td>
<td>8</td>
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</tbody>
</table>

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A fourth procedure was used to investigate various physical sealing mechanisms. Mature hydraulic heads of 0.125, 0.440 and 0.700 m were established over coarse sand columns, with two replicates each for dairy and hog manure. Piezometers were used inside the columns to locate the sealed layers (Fig. 1). Also, total solid contents of 3, 6 and 9% were investigated as to sealing efficiency, over fine sand columns.

Heat-treated and natural dairy slurries (both 6% TS) were compared for infiltration rates over coarse sand columns. The heat-treated dairy slurry was subjected to 121°C for 15 min under 105 kPa of steam pressure. This heat-treated slurry was demonstrating a finer particle size distribution from laboratory analysis using soil screens and a water washing method. This last trial was performed using aluminum tubing 0.048 m in diameter by 0.580 m in height, and a slurry hydraulic head of 0.45 m.

**RESULTS AND DISCUSSIONS**

The comparison of sealing performance between physical and biological mechanisms is presented in Table II. Hog slurries were observed to ferment heavily from the 12th to 48th h of each trial. This biological activity was, by far, greater than that of dairy slurry. This superiority probably resulted from the better biodegradability or lower fiber content of the hog manure solids. The chemical sealing effects were found to be insignificant, as no significant difference was found between the hydraulic conductivities of the clay columns soaked in hog liquids and those soaked in water (Table III).

The use of piezometers during the dairy and hog slurry infiltration trials demonstrated pressure gradient losses directly above and at the soil-manure interface but not below. It was therefore concluded that
the sealing was taking place within the organic mat accumulating over the soil column at the soil-manure interface. This illustrates the basic screening role of the soil leading to the establishment of the impermeable organic mat. The efficiency of the sealing depends on the ability of the soil to retain the manure solids at its surface and to trap them within its surface pores. Soil void geometry and dimension become more important than soil hydraulic conductivity ($k$) with regard to sealing. It also appears that soil particle size distribution, rather than soil $k$, could better describe a soil's ability to become sealed by manure. Soil aggregate size intervenes to a lesser degree as it is believed to be destroyed by biochemical sealed mechanisms such as gleization (Barrington 1985).

Recognizing the importance of the physical sealing mechanisms, their mode of action was further investigated. The use of several different hydraulic heads produced no significant changes on infiltration rates (Table IV, level of confidence exceeding 95%). This was probably the result of a thicker mat formation with increased manure head.

Variations in TS of hog slurries over columns of fine sands failed to produce any conclusive results, as no correlation could be established between infiltration rates after 400 h and manure TS content. Nevertheless, this assay demonstrated that the hog manure mat accumulating at the soil surface had a tendency to gain permeability under cool conditions or under weak biological mechanisms. This occurred through the leaching out of the finer organic particles, manure slurries solids not being uniformly distributed in particle sizes (Table V). Such leaching was not noticed for dairy slurries as the seal probably forms as a randomly deposited fibrous mat consisting of a more even particle size distribution (Table IV). This leaching out process of the hog mat was observed while the slurry was fermenting under warm ambient conditions (over 15°C) during the second day of infiltration. The gas bubbles produced through fermentation agitated the mat, settling the finer particles at the soil surface. Under warm conditions, these fine particles would cake in a solid layer at the soil interface, produce a second mat and strengthen the seal. No such activity was noticed with hog slurry which had been sterilized or for columns under cool temperatures (less than 5°C), thus suggesting the work of biological mechanisms.

Infiltration rates for a dairy slurry of finer particle size solids (heat treated) and of natural, coarser particle size solids, over coarse sand columns, were significantly different (Table VI). Slurry particle size was found to influence physical sealing mechanisms and exfiltrate total organic carbon content (Table VII).

### TABLE V. PARTICLE SIZE DISTRIBUTION FOR MANURE SOLIDS
(Overcash et al. 1983)

<table>
<thead>
<tr>
<th>Manure Type</th>
<th>Particle size distribution for manure solids (%)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>&lt;50 μm</td>
</tr>
<tr>
<td>Hog</td>
<td>45</td>
</tr>
<tr>
<td>Dairy</td>
<td>36</td>
</tr>
<tr>
<td>Poultry</td>
<td>45</td>
</tr>
<tr>
<td>Beef</td>
<td>30</td>
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### TABLE VI. INFILTRATION RATES FOR HEAT-TREATED AND NATURAL DAIRY SLURRIES (6.0% TS)

<table>
<thead>
<tr>
<th>Slurry type</th>
<th>Infiltration rate ($10^{-9} \text{ m/s}$)</th>
</tr>
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<tbody>
<tr>
<td>Heat-treated</td>
<td>1040 ± 260</td>
</tr>
<tr>
<td>Natural</td>
<td>120 ± 44</td>
</tr>
</tbody>
</table>

Range indicates a 95% confidence interval obtained with eight replicates for each slurry type, for infiltration rates after 10 d, and hydraulic head of 0.40 m above the coarse sand column.

Figure 2. Clay columns utilized in the evaluation of chemical sealing mechanisms.
Natural Exfiltrate NH4 NO3 Ca Fe Mg K Na CI
Heat-treated reservoir profiles subjected to a regular cation saturation for the soil of earthen ponds. TABLE VIII illustrates the rate of exfiltrates, respectively. These new levels of ammonia (based upon data from the Quebec Ministry of Environment) gave final liquid cation concentrations of 60 and 280 meq/L. Table IX illustrates the rate of cation saturation for the soil of earthen reservoir profiles subjected to a regular infiltration rate of $8.64 \times 10^{-5}$ m/d ($10^{-7}$ cm/s). Assuming a groundwater table some 60 cm below a hog manure earthen reservoir, contamination would become obvious within 3.3 and 15 yr for sandy and clay soils, respectively. This analysis indicates a need for further groundwater protection for soils of low cation exchange capacity (CEC), even though infiltrations were reduced to $8.64 \times 10^{-5}$ m/d ($10^{-7}$ cm/s).

Column assays throughout the project, indicated a final infiltration rate tending towards $8.64 \times 10^{-5}$ m/d ($10^{-7}$ cm/s). Perhaps this represents the maximum sealing extent of soils in contact with manure.

### CONCLUSIONS

The investigation of individual sealing mechanisms demonstrated the superiority of the physical processes whereby organic solids are trapped within soil pores and at the soil surface. The efficiency of this physical process is a direct function of soil void geometry as well as dimension, and manure solids particle size distribution.

Biological sealing mechanisms intervene as a function of manure solids biodegradability and ambient temperature. This mechanism binds manure solids to soil particles thus strengthening the physical sealing process.

### ACKNOWLEDGMENTS

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### REFERENCES


