

SEALING OF SOILS BY LIQUID CATTLE MANURE

J. L. B. Culley¹ and P. A. Phillips²

¹Land Resource Research Institute, Central Experimental Farm, Ottawa, Ontario K1A 0C6; and
²Engineering and Statistical Research Institute, Central Experimental Farm, Ottawa, Ont. K1A 0C6.

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Earthen manure storages are an inexpensive method of storing liquid livestock wastes in the St. Lawrence Lowlands where climatic conditions require that livestock farmers have sufficient capacity to store in excess of 6 mo of manure production. Percolation tests using liquid dairy manure were performed on soil cores from the parent materials of Kars sand, Grenville loam and Rideau clay to compare their effectiveness as liner material. Hydraulic conductivities of all soil cores decreased to about 0.003 m/day within 5-10 days. The rates of sealing of these soils increased with bulk density; the rate of sealing of the sand was greater than that of the clay or loam. Nitrate plus nitrite N contents of the leachate were generally less than 1 mg/L. Ammonium contents in the leachate from the sand cores were highly variable and averaged about 31 mg/L while those from the clay and loam cores were more constant and had a mean concentration of about 3 mg/L. The results of this laboratory study suggest that the texture of the soil material selected for the liner itself may have little impact on the extent of groundwater contamination beneath earthen pit storages under saturated conditions.

INTRODUCTION

Earth-lined in-ground pits have become a popular method of storing liquid livestock wastes due to their relatively low construction costs (Turnbull et al. 1977). To ensure that there is negligible leakage of manure nutrients, the current design recommendation is that these storages be clay-lined (Canada Plan Service 1979). For many farmers this presents no problem but some, situated on sandy or loam soils, might face considerable extra expense to truck in clay material for a liner. Could their own subsoil be as manure-tight as clay? A laboratory-scale apparatus was set up to test the sealing rate of three soil types, sand, loam and clay, and to investigate the quality of leachate from these soil columns. This research is a component of a long-term study to evaluate potential groundwater contamination from earth-lined manure storages under central Canadian conditions.

MATERIALS AND METHODS

Four soil columns of the parent materials beneath a Kars sand and three columns from a Rideau clay were obtained by driving aluminum cylinders (0.076 m × 0.076 m) into the sides of hand-excavated pits at two sites located on the Central Experimental Farm, Ottawa, Ont. Parent material from beneath Grenville loam was also collected from a site on the Central Experimental Farm, air-dried, and sieved through a 2-mm sieve. (Grenville loam is derived from calcareous stony till, and relatively small columns of such material cannot be obtained undisturbed). Four aluminum cylinders were packed

with sieved till to a dry bulk density of 1250 kg/m³. Bulk densities of the undisturbed sand and clay columns averaged 1500 ± 42 and 1120 ± 14 kg/m³, respectively.

Each core was saturated from the bottom up in a water bath for a minimum of 18 h prior to being mounted in a constant head permeameter device with top-to-bottom flow. Each permeameter was equipped with two mariotte bottles, one filled with water, and the other filled with diluted liquid cattle manure. The properties of the raw liquid manure have been published elsewhere (Culley et al. 1981). To avoid clogging of the connecting lines of the permeameter with manure solids, raw manure was diluted and agitated sufficiently so that it passed through a 40-mesh sieve. Any large, undigested fragments were discarded. This treatment reduced dry matter content from about 9 to 3%.

After each core was mounted in the permeameter, water was passed through the core, under a head of 0.025 m, until a constant flow rate was obtained. The saturated hydraulic conductivity (k_0) of each core was calculated according to Darcy's law

$$k_0 = Q/(A \cdot i) \quad (1)$$

where

k_0 is the saturated water hydraulic conductivity (m/day)

Q is the outflow rate (m³/day)

A is the cross-sectional area of the core (m²)
 i is the hydraulic gradient and is equal to applied head divided by the core length (m/m)

The water line was then closed and the manure line opened; the time and date were recorded. This time (t_0) was taken to be zero in subsequent calculations. All outflow was collected, and weighed at convenient time intervals until the outflow decreased to a negligible rate. Conductivities, k , over the measured time intervals, were calculated using Eq. 1.

Outflow samples were refrigerated at 4°C prior to being analyzed for nitrate plus nitrite (NO₃ + NO₂) and ammonium (NH₄) contents by methods which have been reported elsewhere (Culley et al. 1981).

RESULTS

Preliminary regression analysis of the conductivity data indicated that the following model accounted for the variability of the clay (Fig. 1) and both other soils:

$$\ln k = -a - (b \cdot \ln t) \quad (2)$$

The values of a and b for each soil were determined by least squares regression (Table I). Although this equation yields incorrect predictions of k shortly after initiation of manure loading, more than 90% of the total variability of k for each soil was accounted for by this regression model. The coefficient b is a measure of the rate at which the soil became sealed under the experimental conditions. Paired sample t -tests of the slope coefficient (Steel and Torrie 1960) showed that the b coefficients for the soils were all significantly different from each other ($P < 0.01$). Interestingly, the rates of sealing increased in the order clay < loam < sand, the same order as for

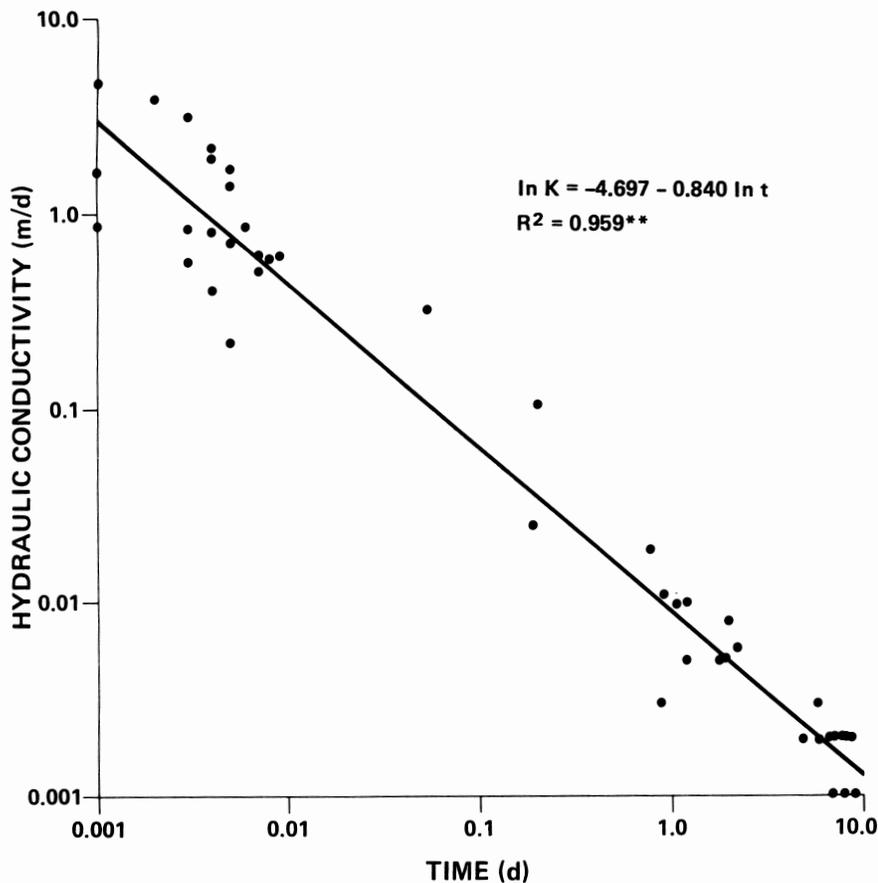


Figure 1. Hydraulic conductivity of Rideau clay columns as a function of time since manure introduction.

the bulk densities and coarseness of texture. At $t=5$ days, both actual and predicted conductivities (k) were similar in all three soils (about 0.003 m/day). Conductivities of soil columns sometimes decline with time when water is passed through columns for extended periods. Thus, these b coefficients may include a component that is not directly due to the sealing effects of the manure, but to experimental factors such as slow reorientation of soil particles.

The inorganic N ($\text{NO}_3 + \text{NO}_2 + \text{NH}_4$) concentrations in the leachate from all columns increased after manure replaced tap water as the influent solution (Table II). Fewer than 10% of the leachate samples had ($\text{NO}_3 + \text{NO}_2$)-N concentrations in excess of 1.0 mg/L. However, a clay or loam column length of only 0.076 m was sufficient to reduce solution inorganic N concentrations by 99.7%. Leachate from one of the sand columns contained very high inorganic N concentrations (121 mg/

L). If this value is excluded, leachate N concentrations from the sand columns are reduced from almost 33 mg/L to less than 0.5 mg/L. There was no apparent reason for the anomalous behavior of this sand column. Also, there was no apparent relationship between inorganic N concentration and the time from initiation of manure loading for any of the soil columns.

DISCUSSION

Biological, chemical and physical mechanisms have been hypothesized as being responsible for the sealing effects of manure on soil columns (Hills 1976). A study of the potential of the gleization process for sealing of earthen water reservoirs (Nicholaichuk 1978) indicated that more than 10 wk were required before hydraulic conductivities decreased by an order of magnitude. Chang et al. (1974) also observed generally small increases in polysaccharide contents in soil cores from beneath a lagoon within 3–7 days of submergence, but much higher values after 64 days. The very rapid declines in conductivity reported here appear to preclude this biological process as the initial sealing mechanism. Chemical dispersal of the clay particles by Na may have occurred in the Rideau clay columns, but the low clay content and very rapid sealing rate of the Kars sand indicate that this mechanism may be of secondary importance.

The observation that the sand had the fastest sealing rate could be explained by its lower porosity compared to the loam and clay. Thus, there may have been more rapid blockage of the relatively large, but less numerous, sand pores compared with the more numerous, but smaller-diameter clay and loam pores. The similarity in conductivities for all materials between 5 and 10 days could be explained if the layer of manure solids which formed on the top of the soil columns controlled the flow rate of liquid through the column.

The proportions of the leachate total inorganic N in the NH_4 form averaged 93, 76 and 66% for the sand, loam and clay soils, respectively. The saturated conditions in the columns, together with manure NO_3 concentrations which made up only about 8% of the total inorganic N content of the manure, probably account for the low NO_3 concentrations in the leachate. Low and high levels of NO_3 and NH_4 , respectively, have been observed in soil columns taken from below and adjacent to earthen storages located in coarse-textured soils (Miller et al. 1976). These authors have noted that elevated soil NH_4 levels may become environmentally haz-

TABLE I. INITIAL SATURATED HYDRAULIC CONDUCTIVITY (k_0) AND BEST FIT REGRESSION COEFFICIENTS RELATING CONDUCTIVITY (k) AND TIME SINCE LOADING OF MANURE ONTO VARIOUSLY TEXTURED SOIL COLUMNS

Soil series	Clay content (%)	Saturated conductivity water (k_0) (m/day)	Regression coefficients†		
			a	b	R^2
Rideau clay	65.5	4.1	4.697 (0.105)	0.840 (0.027)	0.959**
Grenville loam	11.0	2.7	4.572 (0.074)	0.892 (0.022)	0.947**
Kars sand	3.4	14.7	4.243 (0.129)	0.975 (0.035)	0.955**

†The conductivities, k , were regressed against time since manure loading according to the equation $\ln k = -a - (b \cdot \ln t)$. Standard errors for each coefficient are given in parentheses.

**Significant at $P < 0.01$.

TABLE II. NITRATE (NO₃) PLUS NITRITE (NO₂) PLUS AMMONIUM (NH₄) IN LEACHATE FROM VARIOUSLY TEXTURED SOIL COLUMNS

Soil series	Leachate (NO ₃ + NO ₂ + NH ₄) - N (mg/L)			
	Tap water		Liquid cattle manure [†]	
	Mean	Standard error	Mean	Standard error
Rideau clay	0.20	0.04	3.37	1.18
Grenville loam	0.74	0.19	3.31	2.08
Kars sand	0.20	0.02	32.97 [‡]	14.46

[†]Liquid manure contained 1158 mg/L of (NO₃ + NO₂ + NH₄) - N (standard error = 57.4).

[‡]If data from one of the columns are excluded, the mean is reduced to 0.47 mg/L (standard error = 0.23).

ardous if the soil beneath such lagoons is allowed to become aerobic. Observations of commercial-size dairy manure storages, made in conjunction with the present study, have shown that they are not completely emptied and so the storage bottoms remain saturated once manure loadings are commenced. However, drying out of the storage embankments may occur. Also, water table records from a level Rideau clay site near Ottawa (Marshall et al. 1979) indicated that groundwater levels did not recede below about 2 m over a 3 yr period. They also observed that water tables at an Uplands sand site located at the crest of a slope remained within about 4 m of the surface. Uplands, Kars and Grenville soils are all found at similar locations (on higher ground) within the

Eastern Ontario landscape. Thus, at many locations within eastern Ontario, groundwater can be expected to affect soil moisture conditions beneath storages, even assuming that the lagoons become sealed. The results of this laboratory study suggest that the texture of soil material selected for the liner itself may have little impact on the extent of groundwater contamination beneath earthen pit storages under saturated conditions.

Research is currently being undertaken both with small- and commercial-scale earthen storages to evaluate further their pollution potentials in the St. Lawrence lowlands.

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