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Macropore Flow of Liquid Manure

by

R. J. Fleming
Member CSAE
Research Engineer
Agricultural Engineering Section
Centralia College of Agr. Technology
Huron Park, Ontario
N0M 1Y0

S. H. Bradshaw
Research Technician
Agricultural Engineering Section
Centralia College of Agr. Technology
Huron Park, Ontario
N0M 1Y0

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ABSTRACT:

Sixty soil columns were used in this study of macropore flow. They consisted of 30 each of clay loam and sandy loam soil. Each group of 30 was split into 15 each of no-till vs. conventional till soybean land. The soils were all brought to a uniform moisture content. Liquid was then applied to the surface of the columns - manure at 2 rates and a control. The quantity of effluent from the soil columns was not significantly different between the two soil types or between no-till and conventional till. The flow of effluent from the soil appeared to be nearly stopped at 17 hours following treatment, and greater than 50% of the flow occurred during the first 5 hours. A certain amount of bacteria and chemicals in the manure was detected in the effluent.

MACROPORE FLOW OF LIQUID MANURE

R.J. Fleming and S.H. Bradshaw

Various studies have linked the spreading of livestock manure to a degradation in the quality of land-drainage water and surface water (e.g. Evans and Owens, 1972; IJC, 1980; MOE and UTRCA, 1984). Land-spreading continues to represent to the farmer the most practical and efficient way of recycling the nutrients and organic matter contained in manure. Publications such as the Field Crop Recommendations (OMAF, 1990) advise farmers to spread manure based on the nutrient needs of the crop to be grown. This should involve testing the soil to find background levels of certain nutrients.

Unfortunately, even when farmers have followed the advice of printed cropping recommendations or crop consultants, they have sometimes had problems with liquid manure entering field tile drainage systems. This has lead to contamination of surface water. Dean and Foran (1990) reported on liquid manure spread on a variety of farm fields, at rates ranging from 36 m^3/ha to 140 m^3/ha. Significant contamination of tile drainage water occurred at 8 of the 11 sites. The spreading rate appeared to have little to do with this contamination. The most likely pathway for the manure seemed to be large soil pores (macropores).

Normally, water entering a layer of soil displaces water already in that layer. Gradually, the water moves downward through the soil. Preferential flow can occur through soil macropores (i.e. cracks, channels formed by plant roots or worm, or other relatively large voids in the soil). Thus, water and solutes can move through the macropores, bypassing many of the smaller pores. Priebe and Blackmer (1989) found that preferential flow of water through soil macropores was an important factor affecting N movement in Iowa soils. Other researchers have tried to measure macropore flow in soils and develop models for predicting its impact (e.g. Beven and Germann, 1982; Davidson, 1985; Everts and Kanwar, 1989; White, 1985). In a literature review, Miller et al (1989) identified macropore flow of manure as an area requiring additional research.

Miller et al (1989) also recognized that work was needed to identify manure application methods that are compatible with no-till systems. They were mainly concerned about incorporation techniques that would use the nutrients most efficiently yet not disturb the surface residue to any great extent. A further potential problem involves the spreading of liquid manure on the soil surface. No-till fields typically have higher infiltration rates than conventionally-tilled fields (Mostaghimi et al, 1989).

Because of the importance of liquid manure to livestock agriculture, the growing interest in no-till systems, and the lack of information on macropore flow of liquid manure, the following objectives were chosen:

1) Determine to what extent flow of manure through soil macropores occurs under typical Southwestern Ontario conditions.

2) Compare the macropore flow for the soil from two tillage systems - no-till versus conventional tillage.

PROCEDURE

Collection of Soil Columns

A farm was selected that would give the following soil conditions:

a) clay loam soil, no-till
b) clay loam soil, conventional tillage
c) sandy loam soil, no-till
d) sandy loam soil, conventional tillage

All the soils were located in the same field. The field was planted in soybeans during 1990, when the soil columns were collected. Different methods have been tried by researchers to obtain undisturbed blocks of soil. Most of these have used soil depths of only 30 cm or less. The problem addressed by this study involved manure entering drain tiles. Since drain tiles are typically installed at depths of 75 to 90 cm, a means of getting deeper cores was needed. The optimum solution appeared to be the use of 15 cm diameter pipe pressed into the ground using a Meta-Drill machine (Meta-Probe Inc., Picton, Ont.). This machine uses hydraulic pressure to vibrate the pipe straight down into the ground. Because of the vibration, there is very little compaction of the soil. Also, the vibration was of a frequency that appeared to have no effect on the soil structure in the column - it appeared to give "undisturbed" soil columns.

Fifteen columns were collected for each of the 4 soil conditions listed earlier. Each was about 60 cm deep (average depth = 61.4 cm, std. dev. = 1.9). The soil columns were collected between August 1 and August 21, 1990. After the pipes were pushed into the ground, they were simply pulled out. This was done either by using the Meta-Drill machine or by using an electric winch.

Preparation of Soil Columns

As the columns came out of the ground, they were inspected to make sure no soil had fallen out of the bottom end (if soil fell out, the column wasn't used). End caps were fastened to both ends to prevent drying, and the soil was transported to the lab. There, they were stored in a cool dark area for several days (still capped). Each group of 15 soil columns was randomly divided into 3 groups of 5 columns -

representing the 3 treatments.

The following steps were taken to bring the soil columns to a similar moisture content, as close as possible to Field Capacity[1]. On Sept. 4 and 5, 1990, the bottom caps were removed. The bottom of each column was wrapped with filter cloth (geotextile) to prevent soil from falling out. The columns were then stood in pails of tap-water. A depth of 37 cm of water was maintained in the pails for several days. On Sept. 11, the columns were removed from the pails and set on the test rack (see Fig. 1). The filter cloth was left in place for at least 12 hours and the soil was allowed to dry to Field Capacity. On Sept. 12, the filter cloth was removed and about three hours later, the treatments were applied to the soil surface.

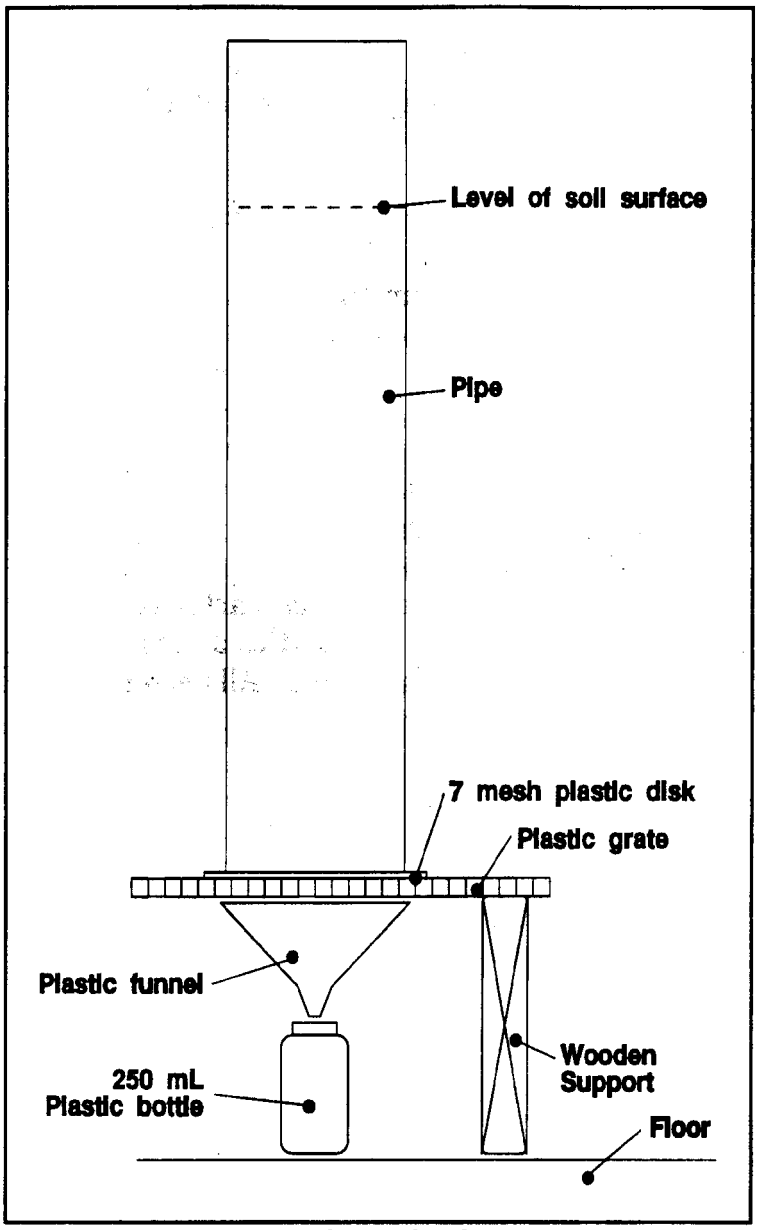

Figure 1 Test setup for soil columns

Applying Manure to Soil

Liquid swine manure was used for the test. Chloride was used as a chemical tracer. Its presence was measured during later chemical analyses. Manure was sprinkled onto the soil surface by pouring it through the sprinkler head from a garden watering can. Treatment 1 consisted of a depth of 10 mm of manure. Treatment 2 was double this amount. Treatment 3 consisted of 10 mm of distilled water. Approximately one hour after these

[1] Field Capacity - the state in the soil where capillary pores are saturated with water and all the water that will drain by gravity is gone from the soil.

treatments were applied, distilled water equal to a depth of 10 mm was added to each of the soil columns.

Manure samples were collected throughout the time manure was being applied to the soil. These were refrigerated for later bacterial and chemical analysis.

Effluent Sampling and Analysis

Effluent dripping from the bottom of the columns was collected in plastic bottles. These bottles were weighed at the following times (after application of the final amount of water): 1 hour, 5 hours, 9 hours, 15 hours, and 17 hours. When the effluent weight exceeded about 30 g, a new bottle was inserted and the sample was capped and refrigerated. After the 17 hours, all bottles were weighed, capped, and refrigerated. Where there was in excess of 30 g of effluent in a bottle, a portion was drawn off into sterilized bottles for bacterial analysis. Effluent that had been refrigerated after only one hour (following treatment) was analyzed for levels of fecal coliform, fecal strep. and *E. coli* bacteria. For the remainder of the samples (i.e. those that had remained in the bottles at room temperature for several hours) only fecal coliform levels were measured. All bacterial analysis was performed within 24 hours of sample collection.

The bottles of effluent destined for chemical analysis were kept refrigerated until they could be analyzed. Due to lab constraints, these were not analyzed for about one month. Levels of nitrate-N ($N0_3$-N), ammonium-N (NH_4-N), water-soluble chloride (Cl), and total solids were measured.

Soil Sampling and Analysis

When the effluent samples were removed, the soil columns were capped and laid on their sides to prevent further downward moisture movement. During the next week, soil samples were taken from each core. The soil column was removed intact from the pipe (the plastic pipes were cut; the soil in the steel pipes was pushed out). Samples of well-mixed soil were taken from the five depths shown in Fig. 2. These samples were refrigerated or frozen and later analyzed for moisture content, NH_4-N, $N0_3$-N, water soluble Cl, pH, phosphorus (P), and potassium (K). The time delay before analysis varied, but was approximately 2 months.

RESULTS AND DISCUSSION

Soil Information

In all cases, it appeared as though there was little or no soil compaction in the soil columns. After the tube was pressed into the soil (before extraction), it was possible to measure the height of soil in the tube relative to the surrounding soil. The greatest depression was about 2 cm. Reducing the vibration frequency of the unit helped reduce compaction, especially in the sandy soil.

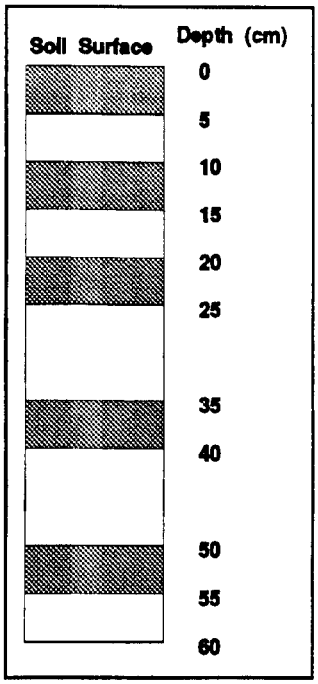

Figure 2 Layers (shaded) in the soil columns which were tested for various chemicals

Effluent Volume

The speed at which liquid moved through some soil columns was dramatic. In some cases, liquid began dripping from the columns within two minutes of application to the soil surface. In other cases, no liquid emerged, even after 17 hours following treatment. The total time needed to apply all three treatments plus the final amount of distilled water was two hours. One hour later, when the bottles of effluent were weighed, 34 of the 60 contained some effluent (>1 g). At the 17 hour mark, this number had risen to 49. This is shown for each soil condition in Figure 3. For the no-till clay soil, only the columns with measurable effluent at one hour had effluent at 17 hours.

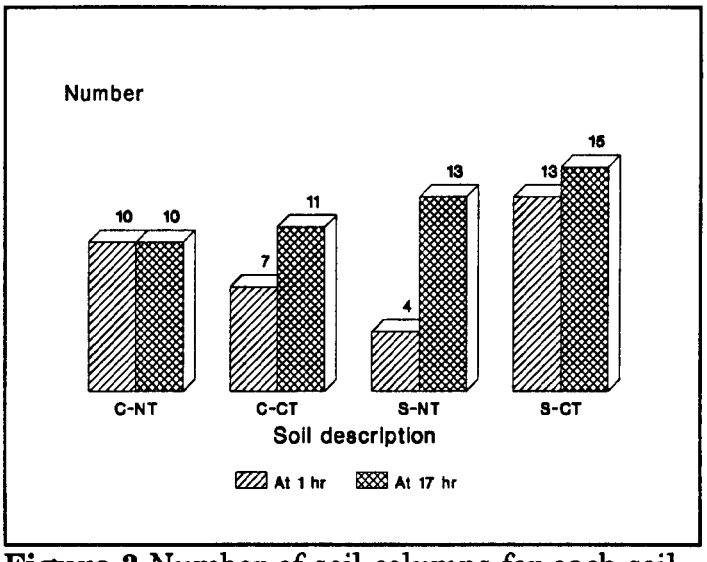

Figure 3 Number of soil columns for each soil condition (out of 15 total) having measurable amounts of effluent at 1 and 17 hours following treatment. (C=clay soils; S=sandy soils; NT=no-till; CT=conventional tillage)

The quantity of effluent (at 17 hours) varied from column to column. There was no significant difference (at p=0.05) in the effluent (as percent of applied) between the two soil types or between the two tillage practices (p values were 0.24 and 0.17 resp.). The amount of effluent for the sand with conventional tillage was significantly higher than for clay with conventional tillage and sand with no-till (p=0.003).

In Figure 4, the differences in treatments are considered. Treatments one and three both involved the application of two g/cm^2 of total liquid; three g/cm^2 of liquid was applied with treatment two. Figure 4 shows the cumulative totals of effluent for the two soil types and the two volumes of liquid applied. Not surprisingly, the soils receiving three g/cm^2 of liquid had higher volumes of effluent than those receiving only two g/cm^2. Also, for each of the four conditions shown, the greatest effluent yield occurred during the first five hours following treatment.

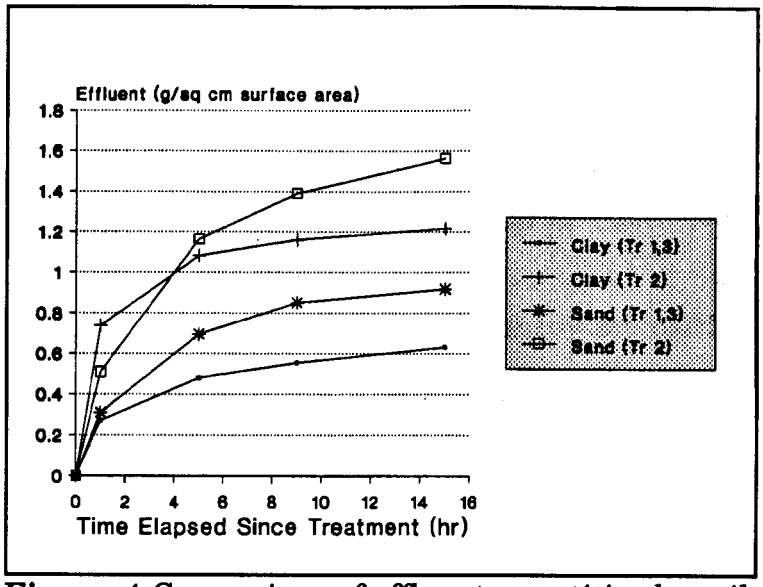

Figure 4 Comparison of effluent quantities by soil type and treatment over time. (Treatment 1,3 equiv. to 2 g/cm^2 applied; Treatment 2 equiv. to 3 g/cm^2)

Bacteria

At the one hour mark following treatment, 20 effluent samples were refrigerated and later analyzed for numbers of fecal coliform, fecal streptoccocus, and *E. coli* bacteria. Subsequent effluent samples were analyzed for only fecal coliform bacteria. These latter samples were all analyzed within 24 hours, but the results were not deemed to be as representative of the actual situation. This is a result of the extended time that the effluent sat in the bottles while at room temperature (up to 17 hours).

In the first group of 20 samples, levels of the three types of bacteria were similar. Therefore, only the numbers of fecal coliform bacteria will be reported. Figure 5 shows the numbers of fecal coliform bacteria in the effluent from the 20 soil columns. The amounts applied for the three treatments are compared to the effluent amounts. (In treatment 3, the control, no bacteria were applied). Geometric mean values are used. The bacteria in the effluent represent 2.6% and 2.2% of the bacteria applied in treatments one and two, respectively - for the 20 soil columns involved.

The two tillage methods did not appear to cause any significant differences in the levels of bacteria in the effluent. However, the two soil types were significantly different (p=0.0002). The geometric mean of the total number of fecal coliform bacteria for the clay soils (only those soil columns have effluent tested for bacteria) was 41 per cm^2 surface area. This compares to 0.31 for the sandy soils (n=19 and 22,

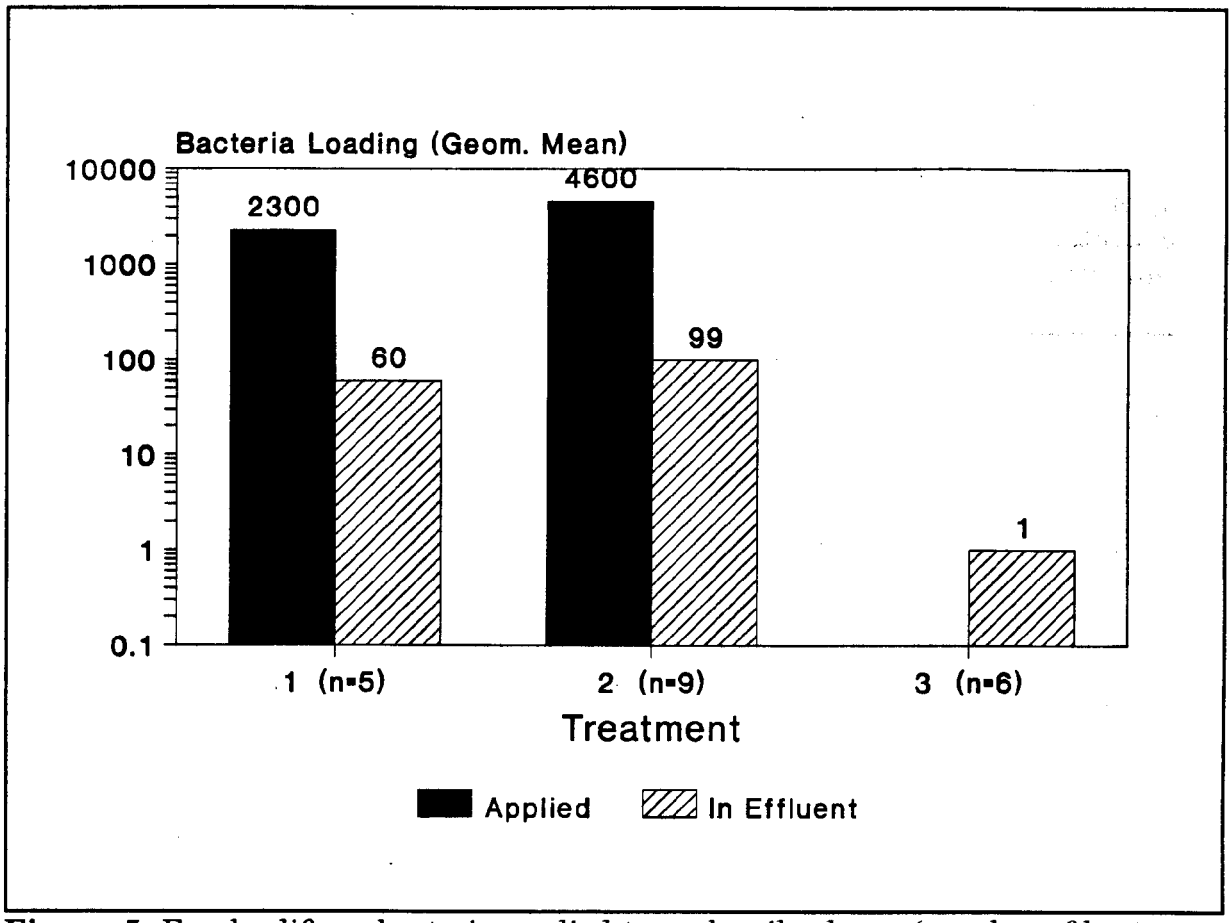

Figure 5 Fecal coliform bacteria applied to each soil column (number of bact. per cm^2) vs. in effluent at 1 hour following treatment - only 20 of the 60 columns had sufficient quantity of effluent for sampling.

resp.). Even though the quantities of effluent were greater for the sandy soils, as discussed earlier, the total numbers of bacteria passing through the soil were less than for the clay soils.

Chloride

The amount of chloride applied to the soil in Treatment 1 was 4.76 mg/cm^2, and for Treatment 2 was 9.52 mg/cm^2. The lab analysis of all liquid samples for chloride levels was performed on a Braun-Lubb Traacs 800 machine (automated ferricyanide technique). Unfortunately, the measured levels of chloride in the manure and in the effluent were much lower than expected. Based on the lab results, the Cl application rates were only 0.69 and 1.37 mg/cm^2 for Treatments 1 and 2, respectively. There is no obvious reason for this discrepancy. The chloride levels for the various soil layers (discussed later) were at or about the predicted levels. This suggests that the lab

results for the chloride levels in the manure (and therefore, the effluent) were incorrect.

The following can be said about the chloride values that were reported by the lab: a) there were no significant differences in total chloride amounts (expressed as mg/cm^2 of soil surface) between soil types or tillage practices; b) the two manure applications did not produce chloride concentrations in the effluent that were significantly different from the control.

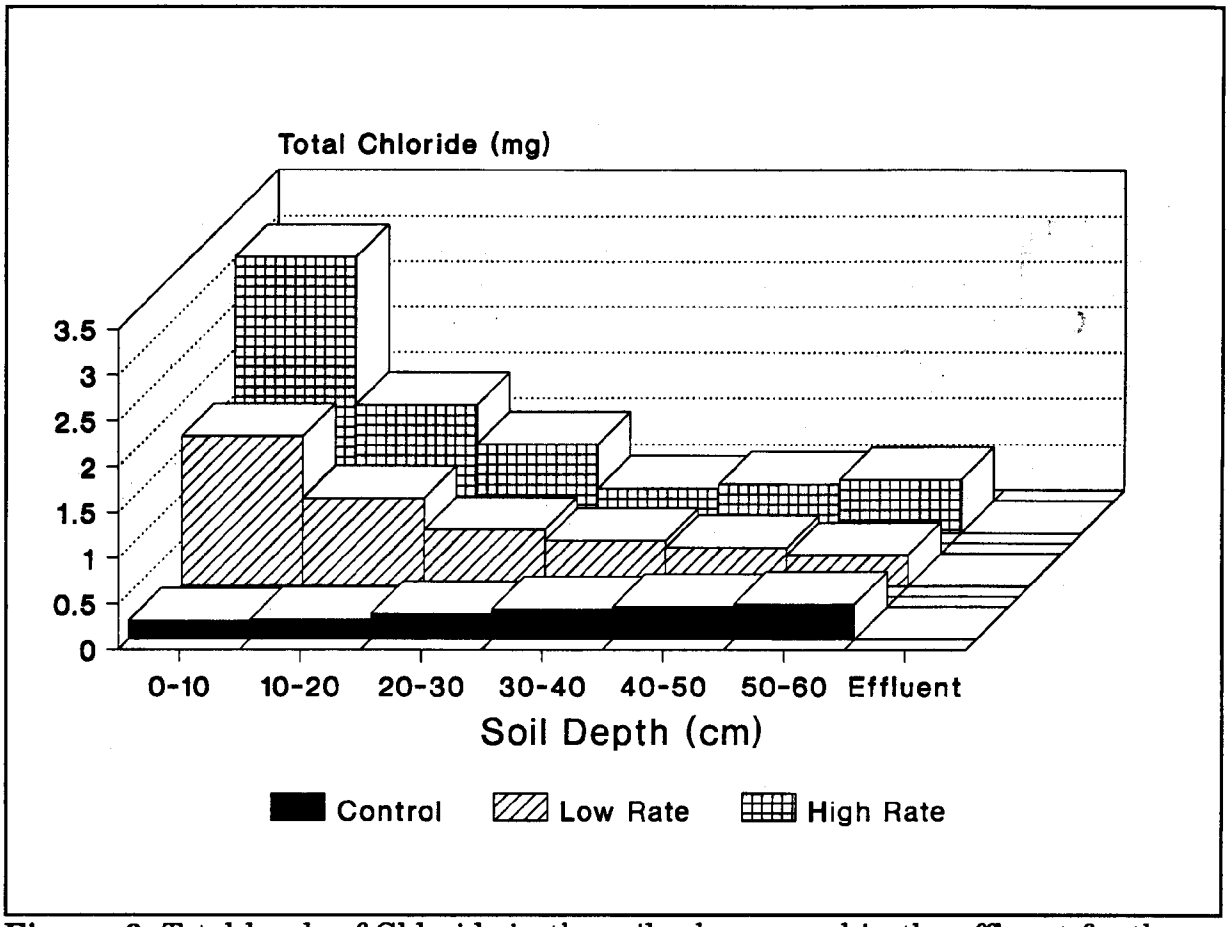

Figure 6 Total levels of Chloride in the soil columns and in the effluent for the clay soils - geom. mean values

Soil concentrations of chloride told a different story. Figure 6 shows the total amounts of chloride in the soil column for the clay soil. Similar results were found for the sandy soil. In both cases, chloride levels were elevated due to the relative amounts added in the two manure application rates. This elevation of levels was most marked at and near the soil surface, but, in the case of the clay soils, extended right through to the bottom of the soil column. Total levels of water soluble chloride in the soil are reported in Table 1. These numbers suggest that approximately 40%

to 60% of the chloride added to the soil surface (based on the "calculated" concentration of chloride in the manure) was subsequently measured in the soil. The remaining amount of chloride cannot be accounted for. Presumably, some quantity greater than what the lab results suggest was present in the effluent.

Table 1: Total levels of chloride in the soil

Chloride in each 60 cm soil column		
	Sandy Soil	Clay Soil
	(mg/cm^2 surface area)	
Soil background levels (control)	5.00	1.78
Effluent background levels	0.008	0.001
Treatment 1		
- Applied	4.76	4.76
- Net addition * to soil	2.0	2.7
- % of applied in soil	42%	57%
- Net addition to effluent	-0.008	-0.0003
- % of applied in effluent	-	-
- Total recovered	42%	57%
Treatment 2		
- Applied	9.52	9.52
- Net addition to soil	5.1	5.2
- % of applied in soil	54%	55%
- Net addition to effluent	0.009	-0.0001
- % of applied in effluent	0.09%	-
- Total recovered	54%	55%

* Net addition = (measured amount) - (background level)

Other Parameters

Levels of nitrate-N ($N0_3$-N) and ammonium-N (NH_4-N) were measured in the manure, soil, and effluent. NH_4-N is considered to be "available" to growing crops. $N0_3$-N is a soluble form that is leached from the soil relatively easily. These are less stable in

the soil than chloride. As a result, the lab results may not provide an accurate representation of the N situation just after manure application. Results of calculations involving these two forms of N are reported in Tables 2 and 3. Here, only 10 to 26% of the NO_3-N and NH_4-N applied can be accounted for. The manure application affected the NO_3-N and NH_4-N levels to a depth of about 30 cm. The results were similar for the sandy soil, with the NH_4-N levels showing even less pattern. In light of the delays prior to lab analysis, the samples should have been analysed for total Kjeldahl nitrogen. This could have been used to prepare a more accurate nitrogen budget. The main reason this was not done was because chloride was used as the chemical tracer.

Table 2: Levels of N as NH_4-N and NO_3 in sandy soil and effluent (geom. mean values)

	NH_4-N	NO_3-N	Total
	(mg/cm^2 surface area)		
Soil background level	0.235	1.072	1.307
Effluent background level	0.00022	0.0027	0.0029
Treatment 1			
- Applied	1.268	0.015	1.283
- Net addition to soil *	0.229	0.019	0.248
- % of applied in soil	18.0%	126.7%	19.3%
- Net addition to effluent	0.00029	0.00088	0.0012
- % of applied in effluent	0.023%	5.87%	0.09%
- Total recovered			19.4%
Treatment 2			
- Applied	2.536	0.031	2.567
- Net addition to soil	0.407	-0.045	0.362
- % of applied in soil	16.0%	-145.2	14.1%
- Net addition to effluent	0.00035	0.0030	0.0034
- % of applied in effluent	0.014%	9.7%	0.13%
- Total recovered			14.2%

* Net addition = (measured amount) - (background level)

Table 3: Levels of N as NH_4 and NO_3 in clay soil and effluent (geom. mean values)

	NH_4-N	NO_3-N	Total
	(mg/cm^2 surface area)		
Soil background level	0.136	0.345	0.481
Effluent background level	0.0001	0.0053	0.0054
Treatment 1			
- Applied	1.268	0.015	1.283
- Net addition to soil *	0.017	0.108	0.125
- % of applied in soil	1.34%	720%	9.74%
- Net addition to effluent	0.016	-0.004	0.012
- % of applied in effluent	1.26%	-	0.94%
- Total recovered			10.68%
Treatment 2			
- Applied	2.536	0.031	2.567
- Net addition to soil	0.183	0.372	0.555
- % of applied in soil	7.22%	1200%	21.6%
- Net addition to effluent	0.111	-0.003	0.108
- % of applied in effluent	4.4%	-	4.2%
- Total recovered			25.8%

* Net addition = (measured amount) - (background level)

The pH level of the soils were measured at the various depths (following treatment). The mean value for the clay soils was 7.80 (S.D = 0.20) and for the sandy soils was 7.67 (S.D. = 0.39).

Soil moisture was measured as the soil was being analysed for chemicals. Ranges in average dry matter content were 73%-82% for the sandy soil and 81%-84% for the clay soil.

Other Observations

One of the initial fears with using the smooth-walled pipe to hold the soil was that any applied liquid would run down the inside of the pipe wall and create its own channels of flow. This did not happen. When the soil was removed from the pipe, it was obvious that none of this short-circuiting occured.

The main macropore pathways in the soils in this study appeared to be worm holes. There was no evidence that large soil cracks played a role in macropore flow in this study. Worm holes were observed in most of the soil columns. These ran vertically and appeared to be continuous to the bottom of the column.

On 8 of the clay columns liquid was ponded on the surface even at 17 hours following liquid application. No effluent emmitted from the bottom of any of these soil columns. It appeared that the surface effectively sealed itself.

SUMMARY

Sixty soil columns were used in this study of macropore flow. They consisted of 30 each of clay loam and sandy loam soil. Each group of 30 was split into 15 each of no-till vs. conventional till soybean land. The soils were all brought to a uniform moisture content. Liquid was then applied to the surface of the columns - manure at 2 rates and a control. Following are the most significant conclusions:

1. The quantity of effluent from the soil columns was not significantly different between the two soil types or between no-till and conventional till. The greatest quantity of effluent was for the sand, conventional tillage.

2. The flow of effluent from the soil appeared to be nearly stopped at 17 hours following treatment, and greater than 50% of the flow occurred during the first 5 hours.

3. At 1 hour following application of liquid to the soil surface, liquid effluent had emitted from 34 of the 60 soil columns.

4. A certain amount of bacteria and chemicals in the manure was detected in the effluent. For the 20 soil columns with the greatest effluent flow at one hour following treatment, just over 2% of fecal coliform bacteria applied was measured in the effluent. The amount of chloride, the chemical used as a tracer, in the effluent was not significantly different for the three treatments (however, problems in the lab analysis of chloride in the liquid samples were suspected).

5. While it appears that some preferential flow (i.e. macropore flow) occurred, it also appeared that raw manure was flowing intact through the soil column - rather, there was some dilution or displacement taking place.

6. The method of extracting soil columns and testing for macropore flow appeared to work well. The soil columns were the maximum depth possible for the machine and soil conditions encountered.

ACKNOWLEDGEMENTS AND DISCLAIMER

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