DEVELOPMENT OF A FIELD PROCEDURE FOR PREDICTING MOVEMENT OF LIQUID WASTES IN SOILS

SECOND PROGRESS REPORT

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By

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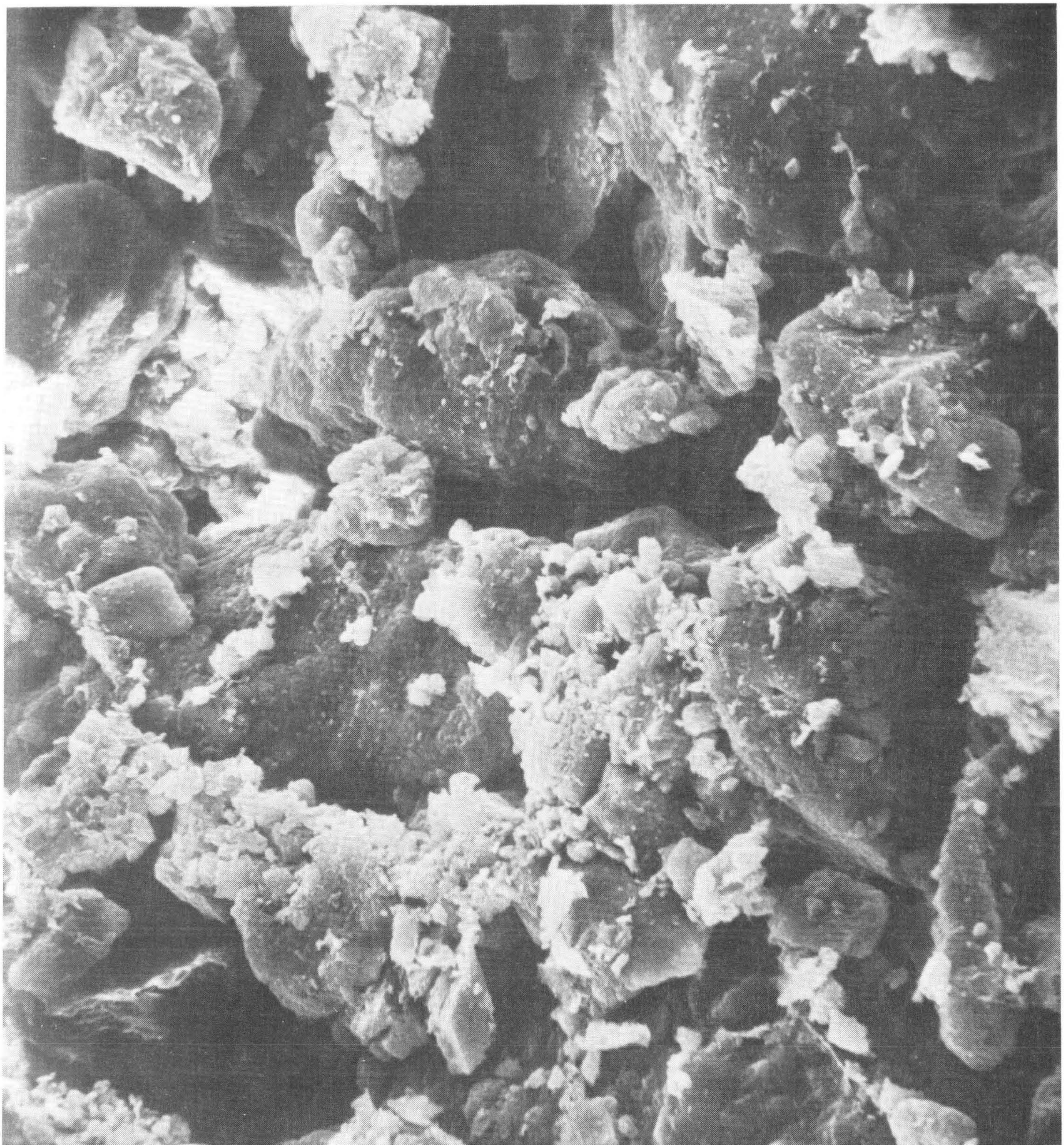
Microfabric of stony sandy loam till (section 3.2)



Photo, courtesy Dr. I. Sachs and Mr. D. Kenny, scanning electron microscope facility, Forest Products Laboratory, Madison, Wisconsin

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Summary

Soil seepage trenches, used for the disposal of effluent from septic systems, were studied at nine locations in as many kinds of soils in Wisconsin. Soil moisture tensions around and below the trenches were relatively low, that is between 10 and 80 mbar, despite the fact that effluent was ponded in the trenches a few inches away. Such a condition can only be explained physically by assuming the presence of a hydraulically resistant organic and/or mineral crust at the boundary layer of trench and surrounding soil (Sec. 3.2.5). The effect is to decrease the potential head at the interface, thus reducing the driving force and decreasing the liquid content (and correspondingly the hydraulic conductivity, K) of the soil. The crusts are composed chiefly of organic substances, formed under anaerobic conditions. These products are broken down, upon aeration, and crust resistance is correspondingly reduced. On the other hand, mineral crusts formed by slaking of soil or compaction of the bed surface during construction, are of permanent nature. Irreversibly iron-cemented mineral crusts were not encountered in this study.

In view of the fact that effluent usually seeps out of septic systems through unsaturated soil, a new field test was developed to measure hydraulic conductivity (K) (which is the infiltration rate when the potential gradient is unity) as a function of water content of unsaturated soil. The test was based on the use of artificial crusts of varying resistance (Sec. 2.3). The resulting data, along with measured potential gradients (Sec. 2.5), made possible an accurate estimation of flow rates of effluent from seepage trenches. These values were much lower than percolation rates measured with the State Percolation Test procedure (Sec. 2.1 and 3.5) and a hydraulic conductivity (K) of saturated soil above the watertable, as measured with the Bouwer double tube apparatus (Sec. 2.2). Replicate state percolation test results at

individual sites had a high coefficient of variability (CV) of 50%, caused by undefined boundary conditions and by the falling head procedure followed in the test. Coefficient of variability was reduced to 35% (Sec. 3.5.2) by maintaining a constant level of water of 15 cm (6") above the gravel. The better defined Bouwer test had a CV of 25%. Measurements made by this test at the same locations in summer and in spring did not show consistent significant differences due to seasonal variation in soil conditions.

The septic seepage fields observed in this study may be characterized with respect to three classes of conditions of soil horizons:

Class 1 Soil horizons with saturated-K values that are too low to accept the effluent flowing into a system at common loading rates, irregardless of effects of crusts. The B3 horizons of the Withee silt loam at Marshfield (Sec. 3.1) and of the Ontonagon silty loam at Ashland (Sec. 3.3) are examples. Consideration may be given to installation of mound or "Nodak" septic systems in order to elevate the zone of discharge of effluent several feet above such soil horizons or above high-standing watertables. The mound consists of man-made overburden of sandy material. Three experimental mound systems were studied in Clark County, Wisconsin and suggestions are made for improvement of design (Sec. 3.6).

Class 2 Soil horizons with satisfactorily high saturated-K values, but with severe crusting problems on the surfaces of trenches. The glacial till under the Saybrook silt loam at the Poultry and Dairy farms at Arlington (Sec. 3.2) is an example. Soil moisture tensions in soil beyond strongly developed crusts were as high as 80 mb, indicating a reduction in infiltration rate into the soil about 300 times below saturated-K values. Ponding of effluent occurred in the trenches. It was found, by emptying a trench of effluent and thereby admitting air to the crusts for two weeks, that the rate of infiltration of effluent subsequently introduced was increased markedly. Intentional application of very high loading rates accelerated ponding of effluent and, within a week's time reëstablished high suctions around 80 mb in the glacial till. This indicates that the actual infiltration rate of effluent into the soil is determined by the loading regime of the septic system. Very low loading rates or dosing of effluent at higher rates are necessary for proper functioning of such systems.

Class 3 Soil horizons with high saturated-K values, and with moderate crusting that does not reduce infiltration to unacceptably low levels. The Plainfield sand at Friendship (Sec. 3.4.2) is an example. In absorption systems that are close to the surface in such a porous soil material, aeration of the soil around the absorption bed may be sufficiently high to obviate total anaerobic conditions. The resulting moderately developed crusts represent a steady state between accumulation and decomposition of organic material that allows infiltration rates to remain at a satisfactory level.

The occurrence of unsaturated flow around seepage beds is very favorable for the disappearance of fecal microorganisms. The effluent was purified in this respect by flow through 15 to 60 cm of soil. On the other hand, chemical pollution, mainly by nitrates and phosphates, persisted in the soil around some of the septic systems studied and appears to be difficult to eliminate.

This progress report defines a number of topics needing further investigation (Sec. 4).

1. Introduction

In the first report on the development of a field procedure to predict the movement of liquid wastes in soil (Bouma et al., 1970) methods were described to test hydraulic properties of soils. Hydraulic conductivity (K) of saturated soil was measured (July-November, 1969) with the Bouwer double tube apparatus in major horizons of seven representative soil pedons in Wisconsin and results were compared with those of the State Percolation test procedure. Some preliminary experiments were made with determination of K values of unsaturated soil horizons in situ. An investigation was begun of quantitative relationships between hydraulic properties and soil morphological features as measured under the microscope.

This second report contains results of field and associated laboratory work in the period of April through October 1970. Measurements were made at eight locations with operating septic tank disposal systems, including permeable sandy and silty soil horizons and also slowly permeable ones over which experimental mound systems had been built. Hydraulic conditions were determined by applying the newly developed crust-test in the field. The Bouwer double tube equipment was used to measure the saturated hydraulic conductivity (K), and percolation rates were determined with the State Percolation Test procedure. Additional soil physical data were obtained by laboratory analyses of undisturbed soil clods and cores.

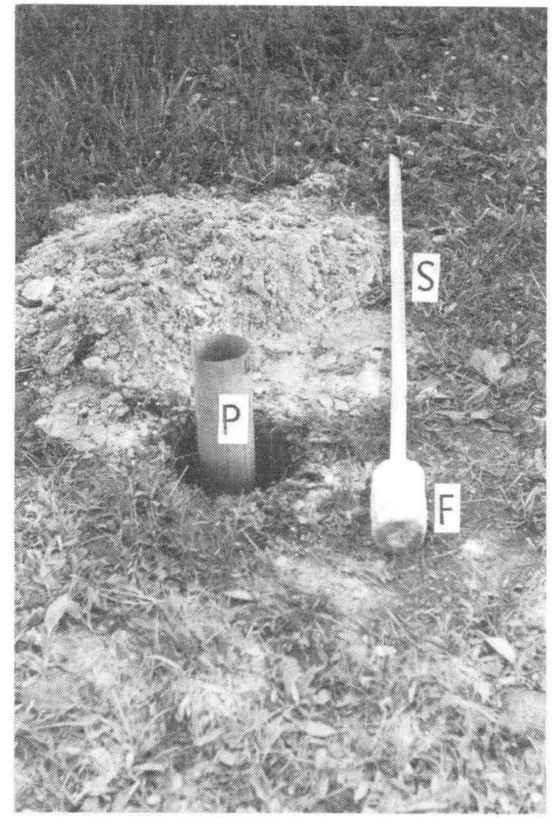
Such data are essential for evaluating flow systems around seepage beds and for making reliable predictions of seepage of effluent. However, a study of liquid waste absorption cannot be restricted to hydrologic conditions because presence or absence of pathologic organisms or undesirable concentrations of nutrients in percolate must be known.

Microbiological analyses of samples of effluents and of soil horizons around the seepage beds were made by Mr. Wayne Ziebell in the laboratory of the Department of Bacteriology, under the immediate supervision of Dr. Elizabeth F. Mc Coy. In addition, some analyses of groundwater samples were made at the U.W. Soil Testing laboratory to determine contents of N and P. The purpose of this study is to obtain a better understanding of physical and biological processes occurring in and around septic tank seepage beds and to apply such knowledge in devising reliable test and monitoring procedures that can contribute to better design and management of soil absorption systems.

Photo 2.1 Percolation test procedures

Percolation test constant level (CLPT)

The waterlevel in the container (C) as visible in gauge (G), is measured frequently to monitor rate of infiltration into the soil. The constant level of water in the hole is maintained by a mariette device, that bubbles air (A) into the entirely closed container.



State Percolation test (SPT)

The water level in the hole is measured with a scale (S) calibrated in inches, that is attached to a float (F) that moves up and down with the waterlevel in the hole. The stovepipe (P) is used for pouring water in the hole and as a support for the float.

2. Methods

2.1. State Percolation Test and Modified Constant Level Percolation Test:

2.1.1. State Percolation Test

A complete description of site evaluation and percolation test procedure can be found in the Register of the State Board of Health, November, 1969, No. 167, Section H 62.20 (private, domestic sewage treatment and disposal systems) and in Chapter H65 (subdivisions not served by public sewers), August, 1968. The chapter on soil tests and site requirements (No. 2) and part of the chapter on the soil absorption system (No. 5) are reproduced here.

Measurements of the water level in the test holes for the State Percolation Test were made using a measuring stick with a scale in inches, mounted on a float that followed the movement of the water level in a stovepipe placed in the hole (Photo 2.1). Graphs were drawn (see examples in Chapter 3.5) showing the downward movement of the water level as a function of time.

2.1.2. Constant Level Percolation Test

The percolation rate, measured with the State Percolation Test, is based on the rate of downward movement of the water level in the test hole in specified time periods. The varying water level makes the test rather complicated, and increases the variability of test results (Section 3.5). We decided, therefore, to modify the test by maintaining the water level in the hole at a constant level. Test holes were similar to those used for the State Percolation Test. A mariotte device was used to maintain a constant water level in the hole (Fig. 2.1). Water flowed into the hole through the plastic tube from an otherwise sealed 5 gallon container that was mounted on a stake driven into the soil. Outflow from the container was measured regularly by observing the water level in a small external transparent sealed plastic tube connecting the upper and lower parts of the container (Photo 2.1). Graphs (Section 3.5) show the cumulative infiltration (in mm) in the soil as a function of time. A discussion of test results is given in Section 3.5.

CONSTANT LEVEL PERCOLATION TEST

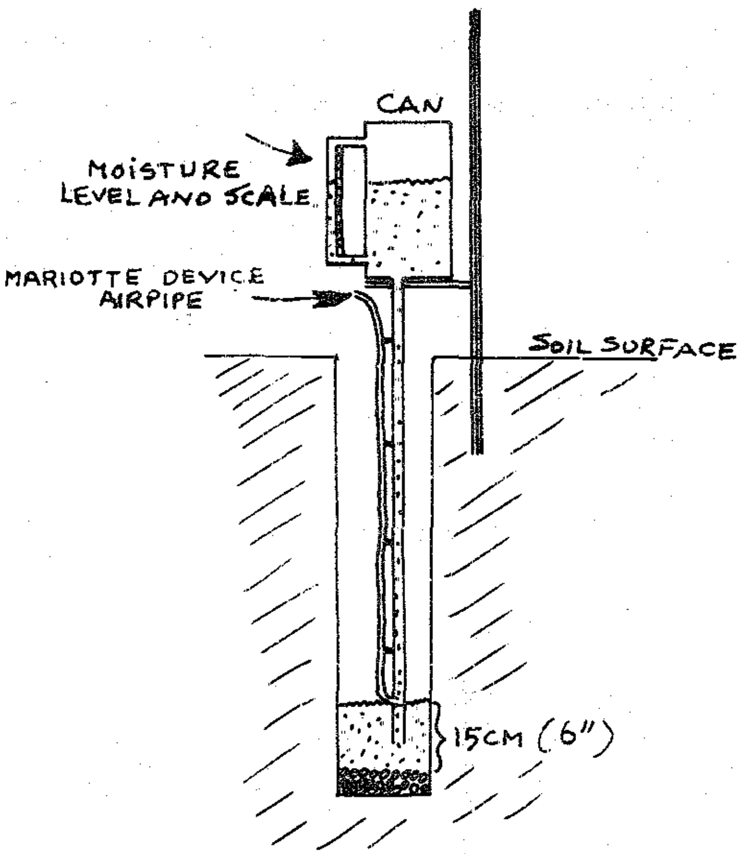


Fig. 2.1

(2) SOIL TESTS AND SITE REQUIREMENTS. (a) *Soil tests supervision.* Soil boring and percolation tests shall be made by or under the direction and control of a master plumber, or master plumber restricted licensed in Wisconsin to install private sewage disposal systems or an engineer, architect, surveyor or sanitarian registered in Wisconsin. Certification of the tests shall be signed by the person providing supervision and control on blank forms furnished by the department.

(b) *Percolation and boring tests.* The size and design of each proposed soil absorption system shall be determined from the results of soil percolation tests and soil borings conducted in accordance with this section. At least 3 percolation tests shall be conducted with the holes located uniformly over the area and to the depth of the proposed absorption system. At least 3 soil borings shall be dug to a depth at least 3 feet below the bottom of the proposed system. The borings shall be distributed uniformly in the area of the proposed system.

(c) *Septic tank location.* No tank shall be located within 5 feet of any building or its appendage, 2 feet of any lot line, 10 feet of any cistern, 25 feet from any well, reservoir, swimming pool or the high water mark of any lake, stream, pond or flowage. Where practicable, greater distances should be maintained.

(d) *Soil absorption site.* 1. Location. All soil absorption disposal systems should be located at a point lower than the surface grade of any nearby water well. The soil absorption system shall be located not less than 25 feet from any building, dwelling or cistern, 50 feet from any water well, reservoir or swimming pool, 5 feet of any lot line, 25 feet of any water service or 50 feet of the high water mark of any lake, stream or other watercourse. Where possible, greater distances should be maintained.

2. Percolation rate—trench or bed. A subsurface soil absorption system of the trench or bed type shall not be installed where the average percolation rate of the 3 tests for the site is slower than 60 minutes for water to fall one inch.

3. Percolation rate—seepage pit. For a seepage pit, percolation tests shall be made in each vertical stratum penetrated below the inlet pipe. Soil strata in which the percolation rates are slower than 30 minutes per inch shall not be included in computing the absorption area. The average of the results shall be used to determine the absorption area.

4. Flood plain. A soil absorption system shall not be installed in a flood plain.

5. Slope. The soil absorption system shall be constructed on that portion of the lot which does not exceed the slope here specified for the class. In addition, the soil absorption system shall be located at least 20 feet from the top of the slope.

Class	Minutes Required for Water to Fall One Inch: Shallow Absorption Systems	Minutes Required for Water to Fall One Inch: Deep Absorption Systems	Slope
1	Under 3	Under 2	20%
2	3 to 45	2 to 30	15%
3	45 to 60	30 to 60	10%

6. Filled area. A soil absorption system shall not be installed in a filled area unless written approval is received from the department.

7. Ground water and bedrock. There shall be at least 3 feet of soil between the bottom of the soil absorption system and high ground water or bedrock.

(3) PERCOLATION TEST PROCEDURE. (a) *Type of hole.* The hole shall be dug or bored. It shall have vertical sides and have a horizontal dimension of 4 to 12 inches.

(b) *Preparation of hole.* The bottom and sides of the hole shall be carefully scratched with a sharp pointed instrument to expose the natural soil interface. All loose material shall be removed from the bottom of the hole which shall then be covered with 2 inches of coarse sand or gravel when necessary to prevent scouring.

(c) *Test procedure, sandy soils.* For tests in sandy soils containing little or no clay, the hole shall be carefully filled with clear water to a minimum depth of 12 inches over the gravel and the time for this amount of water to seep away shall be determined. The procedure shall be repeated and if the water from the second filling of the hole at least 12 inches above the gravel seeps away in 10 minutes or less, the test may proceed immediately as follows: Water shall be added to a point not more than 6 inches above the gravel. Thereupon, from a fixed reference point, water levels shall be measured at 10-minute intervals for a period of one hour. If 6 inches of water seeps away in less than 10 minutes, a shorter interval between measurements shall be used, but in no case shall the water depth exceed 6 inches. The final water level drop shall be used to calculate the percolation rate. Soils not meeting the above requirements shall be tested as in subsection (d) below.

(d) *Test procedure, other soils.* The hole shall be carefully filled with clear water and a minimum water depth of 12 inches shall be maintained above the gravel for a 4-hour period by refilling whenever necessary or by use of an automatic siphon. Water remaining in the hole after 4 hours shall not be removed. The soil shall be allowed to swell not less than 16 hours or more than 30 hours. Immediately following the soil swelling period, the percolation rate measurements shall be made as follows: Any soil which has sloughed into the hole shall be removed and water shall be adjusted to 6 inches over the gravel. Thereupon, from a fixed reference point, the water level shall be measured at 30-minute intervals for a period of 4 hours unless 2 successive water level drops do not vary by more than $\frac{1}{16}$ of an inch. The hole shall be filled with clear water to a point not more than 6 inches above the gravel whenever it becomes nearly empty. Adjustment of the water level shall not be made during the last 3 measurement periods except to the limits of the last measured water level drop. When the first 6 inches of water seeps away in less than 30 minutes, the time interval between measurements shall be 10 minutes and the test run for one hour. The water depth shall not exceed 6 inches at any time during the measurement period. The drop that occurs during the final measurement period shall be used in calculating the percolation rate.

(e) *Verification.* 1. Physical characteristics. Depth to high ground water and bedrock, ground slope and percolation test results shall be subject to verification by the department. Verification of high ground water shall include, but not be limited to, a morphological study of soil conditions with particular reference to soil color and sequence of horizons.

2. Filling. Where the natural soil condition has been altered by filling or other attempts to improve wet areas, verification may require observation of high ground water levels under saturated soil conditions.

(5) SOIL ABSORPTION SYSTEM. (a) *Disposal of tank effluent.* The effluent from septic tanks shall be disposed of by soil absorption systems or by such other manner approved by the department.

(b) *Sizing—residential.* The area required for a soil absorption system serving residential property shall be determined from the following table using soil percolation test data:

Percolation Rate Minutes Required for Water to Fall One Inch	Minimum Absorption Area in Square Feet Per Bedroom			
	Normal Plumbing Fixtures	With Garbage Grinder	With Automatic Washer	With Both Grinder and Automatic Washer
Less than 3	50	65	75	85
3 to 10	100	120	135	165
10 to 30	150	180	205	250
30 to 45	180	215	245	300
45 to 60	200	240	275	330

(c) *Sizing—Other.* The required area for a soil absorption system serving installations other than residential property shall equal the absorption area specified for normal plumbing fixtures according to the percolation test results multiplied by the applicable unit specified in column 2, multiplied by the applicable factor in column 3 of the following table:

Column 1 Building Classification	Column 2 Units	Column 3 Factor
Apartment buildings	1 per bedroom	1.0
Assembly hall—no kitchen	1 per person	0.02
Bar and cocktail lounge	1 per patron space	0.2
Bowling alley	1 per bowling lane	2.5
Bowling alley with bar	1 per bowling lane	4.5
Camps, day use only	1 per person	0.2
Camps, day and night	1 per person	0.45
Camp ground and camping resort	1 per camping space	0.9
Church—no kitchen	1 per person	0.04
Church—with kitchen	1 per person	0.09
Dance hall	1 per person	0.06
Dining hall—kitchen and toilet	1 per meal served	0.2
Dining hall—kitchen only	1 per meal served	0.1
Drive-in restaurant	1 per car space	0.6
Drive-in theater	1 per car space	0.1
Factories, office buildings, exclusive of industrial waste	1 per person	0.4
Hotels or motels and tourist rooming houses	1 per room	0.9
Hospital	1 per bed space	2.0
Migrant labor camp—central bath house	1 per employee	0.25
Mobile home park	1 per mobile home site	2.0
Nursing and rest homes	1 per bed space	1.0
Parks—toilet waste only	1 per acre	4.0
Parks—showers and toilets	1 per acre	8.0
Restaurant—kitchen and toilet	1 per seating space	0.6
Retail store	1 per employee	0.4
Retail store	1 per customer	0.03
Self-service laundry—toilet wastes only	1 per machine	1.0
Service station	1 per car served	0.15
Swimming pool bath house	1 per person	0.2
School—no meals, no showers	1 per classroom	5.0
School—meals served or showers	1 per classroom	6.7
School—meals and showers	1 per classroom	8.0

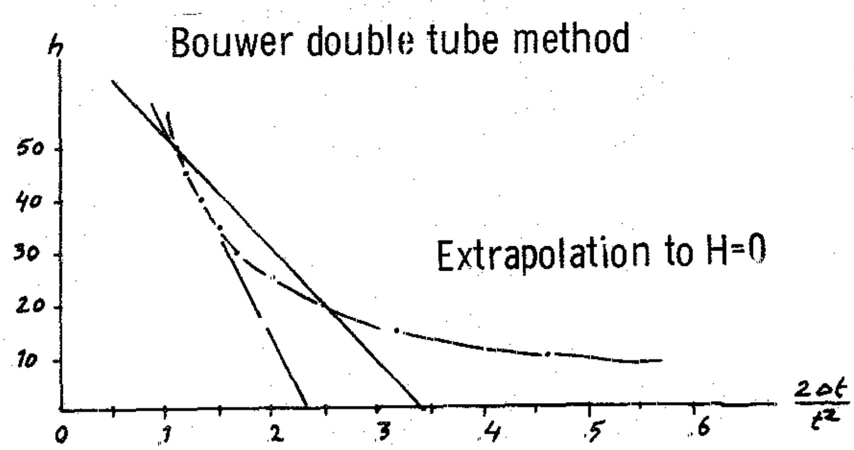


Fig. 2.2.1

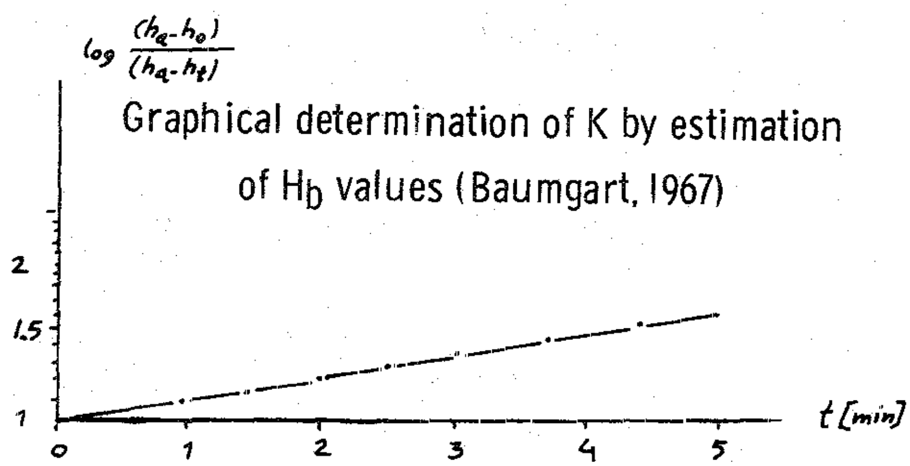


Fig. 2.2.2

2.2. The Bouwer Double Tube Method

This test has been described earlier (Bouma et al., 1970). The calculation of K values, according to the procedure outlined by Bouwer (1961), may be difficult because of the rather inaccurate procedure of extrapolation (see Fig. 2.2.1). Problems can be reduced when the total drop H of the water level in the inner tube standpipe (ITS) is varied for different measurements, so as to create a difference between the equal level and OTS-full times of approximately 8 sec. For example, in soils with a high infiltration, it may be necessary to extend the measurement to H = 80 cm, instead of the usual 40 cm. Baumgart (1967) made a study of the Bouwer method and suggests a somewhat modified procedure of calculation, that is based on the Bouwer calculation with an available H_b value.

H_b is the difference in cm between the top of the outer tube standpipe (OTS) and the water level at balanced flow conditions, when $Q_I = Q_H$, where Q_I is the flow leaving through the bottom of the inner tube due to intake and Q_H = flow, entering through the bottom of the inner tube due to a difference H between the water levels in inner and outer tube. Then:

$$K = \frac{2.3 R_v^2}{R_c F_f t} \cdot \log \frac{H_o - H_b}{H_t - H_b} \quad \text{(Bouwer, 1961)}$$

where R_v = radius of inner tube standpipe, R_c = radius of inner tube, F_f = flow factor, t = elapsed time, H = distance of water level in the inner tube below water level in the outer tube H_b = H at balanced flow. This equation can only be applied when H_b can be measured. Mostly this is not the case and then the OTS-full and equal-level measurements are made (Bouwer, 1961). Baumgart (1967) suggests that this formula be used in all cases, and to estimate H_b values until the plotted values of t and log H_o-H_b/H_t-H_b are on a straight line. With some practice this can be done rather easily and quickly (see

Fig. 2.2.2, from: Baumgart, 1967). K values calculated by this procedure compared well, with those, obtained with the OTS-full-equal level procedure. We will apply this calculation method in future measurements, because it saves time and is applicable to any type of test result.

2.3. Field measurement of unsaturated hydraulic conductivity by infiltration through artificial crusts

2.3.1. Introduction

The solution of many problems associated with soil water flow depends upon knowledge of the hydraulic conductivity, K. As yet there appears to be no universally reliable way to obtain K from more fundamental physical measurements such as particle-size or pore-size distribution. Hence K must generally be measured experimentally.

Of the numerous methods which have been proposed for this measurement (Klute, 1965a, b; Boersma, 1965a, b), the <u>in situ</u> methods must be regarded as inherently preferable as they are more directly applicable to the solution of field problems. Satisfactory procedures are now available for the <u>in situ</u> measurement of hydraulic conductivity under saturated conditions (K_{sat}), both below and above the water table (Bouwer, 1962). However, in many cases the flow regimen is such that the soil is unsaturated. In the presence of an impeding layer at the surface or in the presence of very low precipitation rates, the soil profile may never become saturated during infiltration, and the flow rate will be governed by the soil's unsaturated hydraulic conductivity which is, itself, a function of the matric suction prevalent in the soil.

Processes of infiltration into crust-capped profiles were recently studied by Hillel and Gardner (1969, 1970a). They reported that an impeding layer or crust at the top of an infiltrating profile causes a potential head loss at that point. Thus, if water head over the crust is kept small, it is possible to maintain infiltration into an unsaturated column yet retain the experimental advantages of easily measured inflow rate afforded by a flood infiltrometer. This finding formed the basis of a proposed method for measuring the unsaturated hydraulic conductivity at different suction and water-content values, which Hillel and Gardner (1970b) checked with artificially-packed laboratory columns, but not in the field.

This sect. describes the results of trials designed to test the applicability of this method in the field.

2.3.2. Methods

The method described by Hillel and Gardner for measuring the hydraulic transmission properties of a profile, as a function of water content or suction, involves a series of infiltration trials through capping plates (or crusts) of different hydraulic resistances. The effect of this resistance is to prevent saturation at the subcrust boundary even though the crust itself is subject to a small positive head. Though estimates of K and D (the diffusivity) can be obtained during the transient stage of infiltration, the most reliable measurements are obtained by allowing the infiltration process to proceed to a steady state, when the flux becomes equal to the conductivity. The use of a series of crusts of progressively lower resistance can give progressively higher K-values corresponding to higher water contents up to saturation. Such a series of tests can be carried out if the soil is initially fairly dry, either successively in the same location or concurrently on adjacent locations.

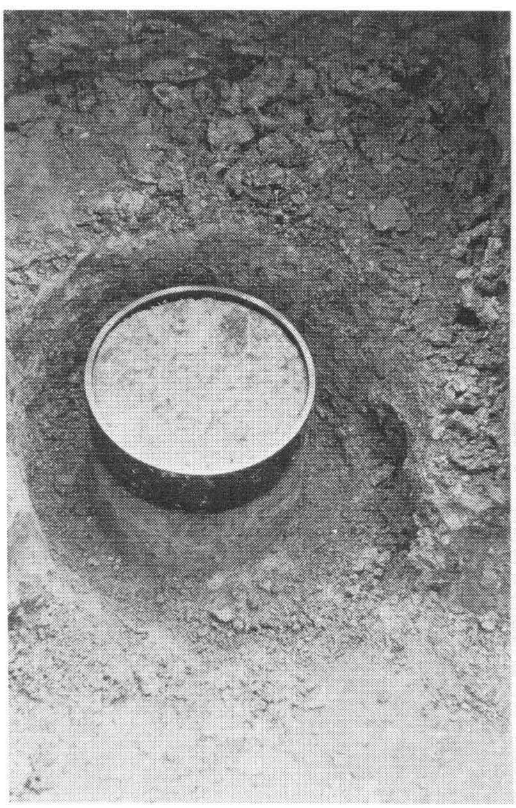
The surface impedance can be applied either by means of a porous plate (e.g., ceramic) or by forming a continuous layer of puddled (slaked or compacted) soil material over the soil surface. Once this layer is established, water is applied (e.g., in a ring infiltrometer) and a small, constant head is maintained over the soil surface long enough for the inflow rate to become steady. This flow rate is equal to the conductivity in a one-dimensional flow system where the suction gradient below the crust is negligibly small (i.e. the hydraulic gradient tends to unity).

Tensiometric measurements on columns of different depth showed that in order to obtain a one-dimensional vertical flow system it was necessary to create an impervious boundary around a column at least 30 cm deep. A steel-cylinder was used at the top of the column to support the small head of water over the crust, to provide a rigid sealing surface for the edges of the crust and to provide a guide for positioning tensiometers below the crust. Below the cylinder an aluminum foil moisture barrier sufficed, since saturated flow would not occur. Use of the foil also made the method applicable to stony soil. Hydraulic conductivity values were calculated from infiltration rates into capped columns and soil suction gradients below the crusts, if any.

2.3.3. Procedures

Tests were made at several sites in Wisconsin. The soils ranged in texture from sand to clay. At each site, a horizontal plane was prepared by using a putty knife and a carpenter's level. A cylindrical column of soil, at least 30 cm high, with a diameter of 25 cm, was carved out from the test level downward, taking care to chip or pick the soil away from the column as the desired boundary was approached, so as to prevent undue disturbance of the column itself (Photo 2.3.3a). A ring infiltrometer, 25 cm in diameter and 10 cm high, was fitted on top of the column (Photo 2.3.3b). The sides of the column were then sealed with aluminum foil and soil was packed around it 2.3.3d). An acrylic plastic cover with a thin rubber gasket glued to it was bolted to the top of the infiltrometer. An intake port and bleeder valve were provided in the cover (Photo 2.3.3d).

Photo 2.3.3a Cylindrical column of soil, 30 cm high and with a diameter of 25 cm, carved out from the test level downward in situ.



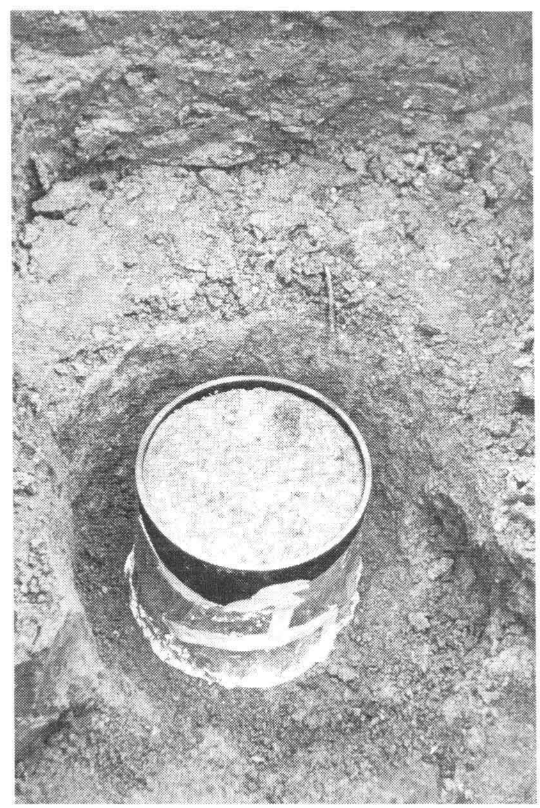
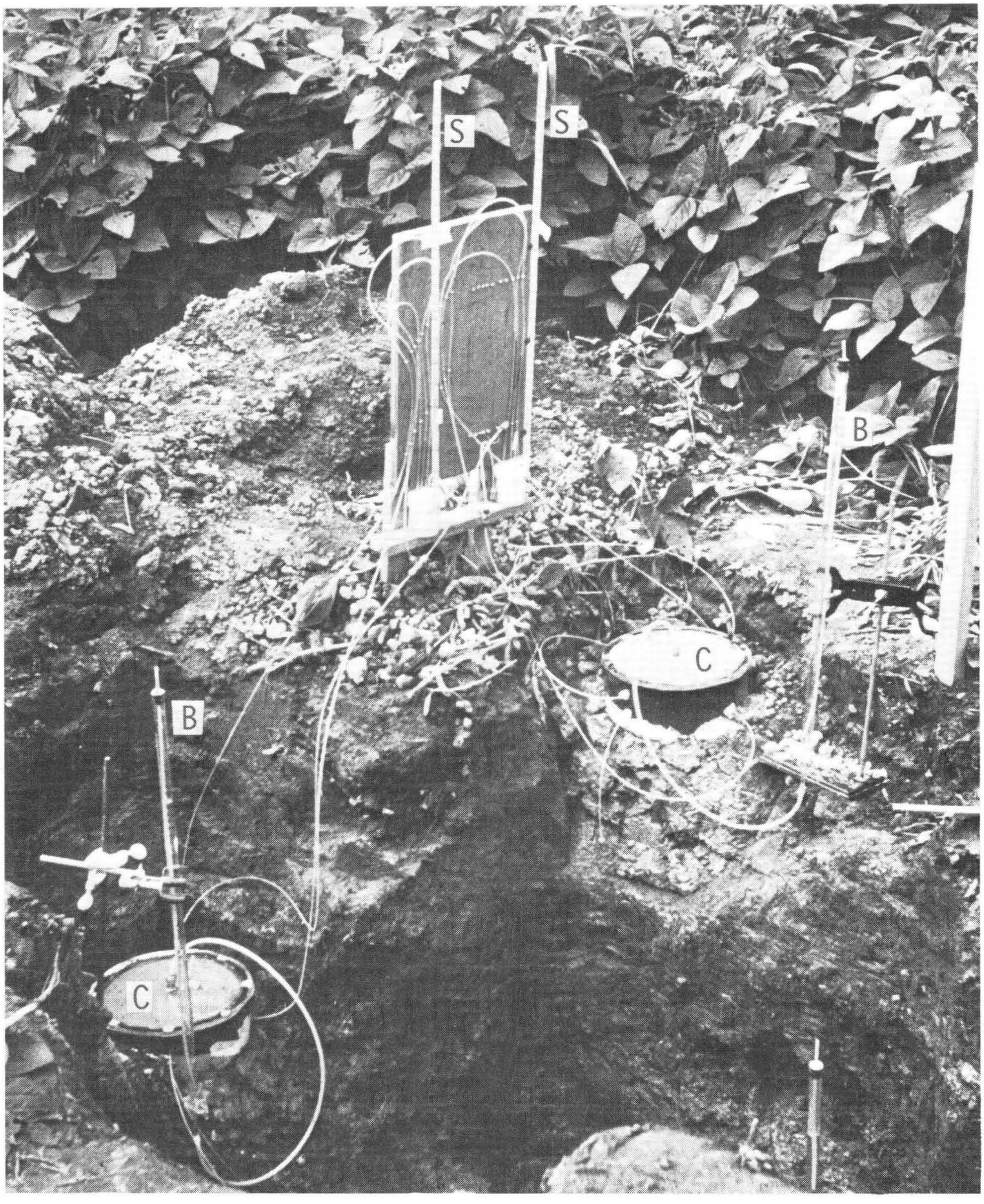


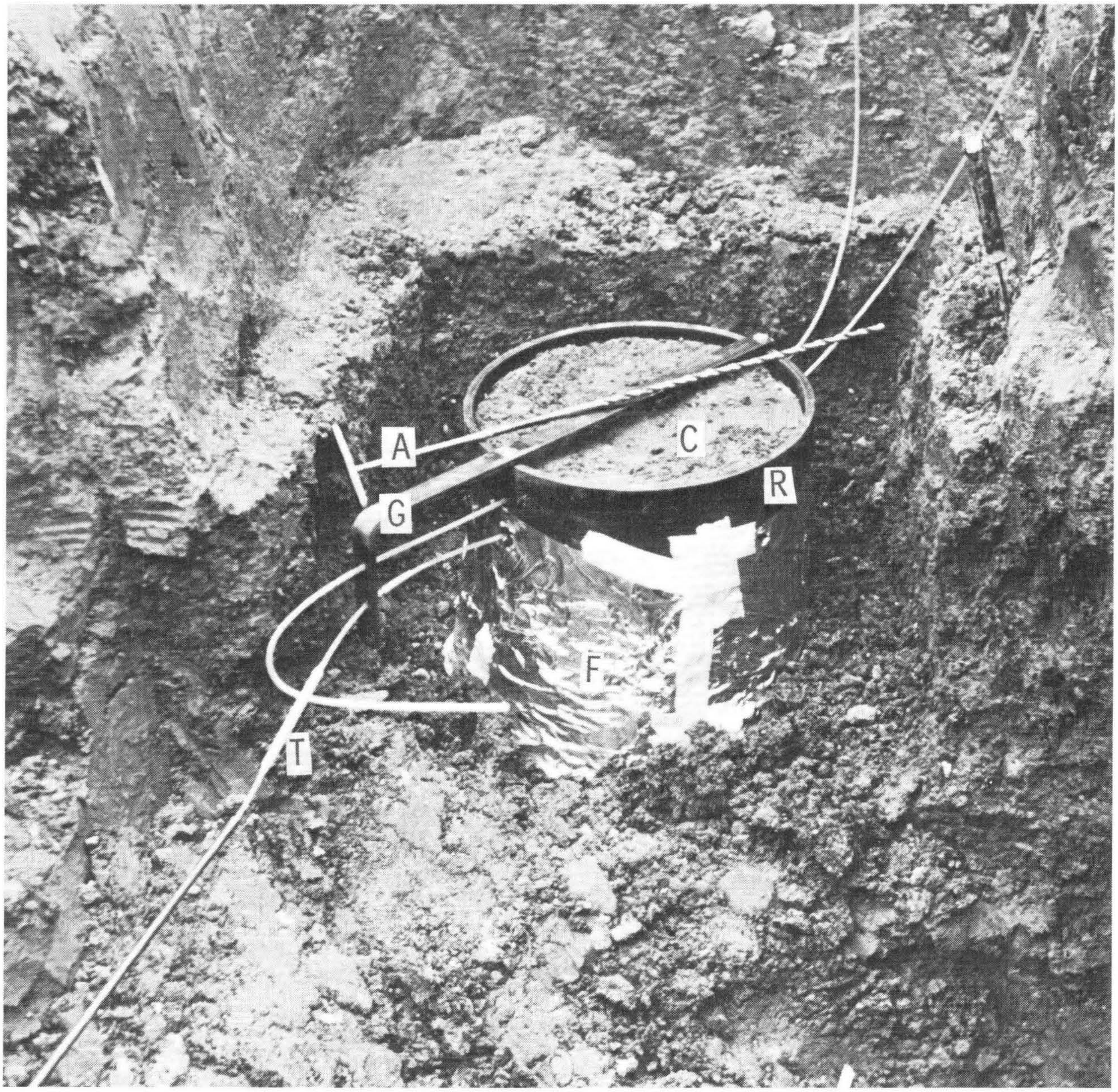
Photo 2.3.3c Sides of the column sealed with aluminum foil.

Photo 2.3.3b A ring infiltrometer, 25 cm in diameter, and 10 cm high, placed on top of the column and extending 2 cm above the soil surface.



Field measurement of unsaturated K in natural soil horizons. Inflow into the soil through the crust is measured with a burette (B) discharging into the water filled space between the crust and the acrylic plastic cover (C). Soil moisture tensions derived from the mercury rise in 1/8" plastic tubes along calibrated scales (S), are measured at three points in the column.

FIG. 2.3.3.d



Preparation of soil column.

The column, with a ring infiltrometer (R) on top, was sealed with aluminum foil (F). Tensiometers (T) are positioned in the column below the crust in holes, prepared with a small auger (A), using an external guide (G). Successive crusts will be applied on top of the soil column (C).

FIG. 2.3.3.e

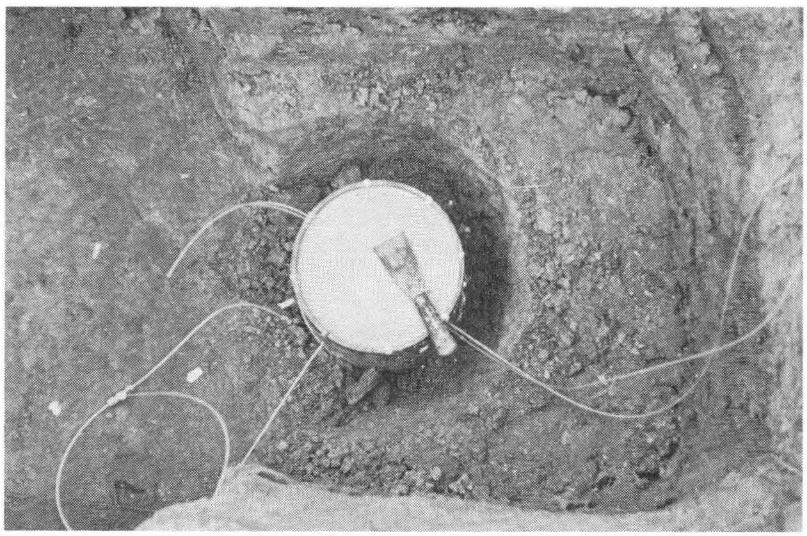


Photo 2.3.3f View of the top of a soil column, like that in Figure 2.3.3c, over the surface of which a "crust" has been spread with the putty knife. "Crust" materials are prepared for spreading by wetting and kneading samples taken from a variety of soil horizons to a homogeneous thick paste.

Thin pencil-size mercury-type tensiometers were placed just below the crust in the center of the column and 3 cm deeper, both in the center and near the periphery of the column. Carefully positioned holes in the steel infiltrometer ring and external installation guides aided in positioning the tensiometers (Photo 2.3.3e). Crusts were formed by wetting and kneading or stirring various soil materials to a homogeneous thick paste, which was spread evenly over the soil surface inside the infiltrometer (Photo 2.3.3f). Special care was taken to seal the crust to the wall of the cylinder to avoid boundary flow. Crusts of this type were applied to the same column in several thicknesses for succeeding runs. Each infiltration run through a particular crust yielded one point of a curve of hydraulic conductivity versus soil suction (Fig. 2.3.4). The small space between the crust surface and the cover of the cylinder was kept full of water. A Mariotte device, in a burette, maintained a constant pressure of about 3 mm water over the crust (Photo 2.3.3d). The infiltration rate into the soil, corresponding to the rate of movement of the water level in the burette, was recorded as soon as the tensiometers showed that equilibrium had been reached. This infiltration rate, when constant for a period of at least 4 hours, was taken to be the unsaturated K-value at the subcrust suction, when the suction gradient was zero. In some cases a suction gradient remained at steady state conditions. Hydraulic conductivity was then calculated according to: $K = v/i$, where v = infiltration rate and i = hydraulic gradient below the crust (in such a case $\neq 1$).

2.3.4. Results

Figure 2.3.4. gives the hydraulic conductivity versus suction curves for some horizons of four soils. These curves could be extended farther into the dry range, but this would take more time and requires that the soil be initially quite dry. The hydraulic conductivity values for saturated soil, measured with the Bouwer Double Tube apparatus corresponded well with infiltration rates

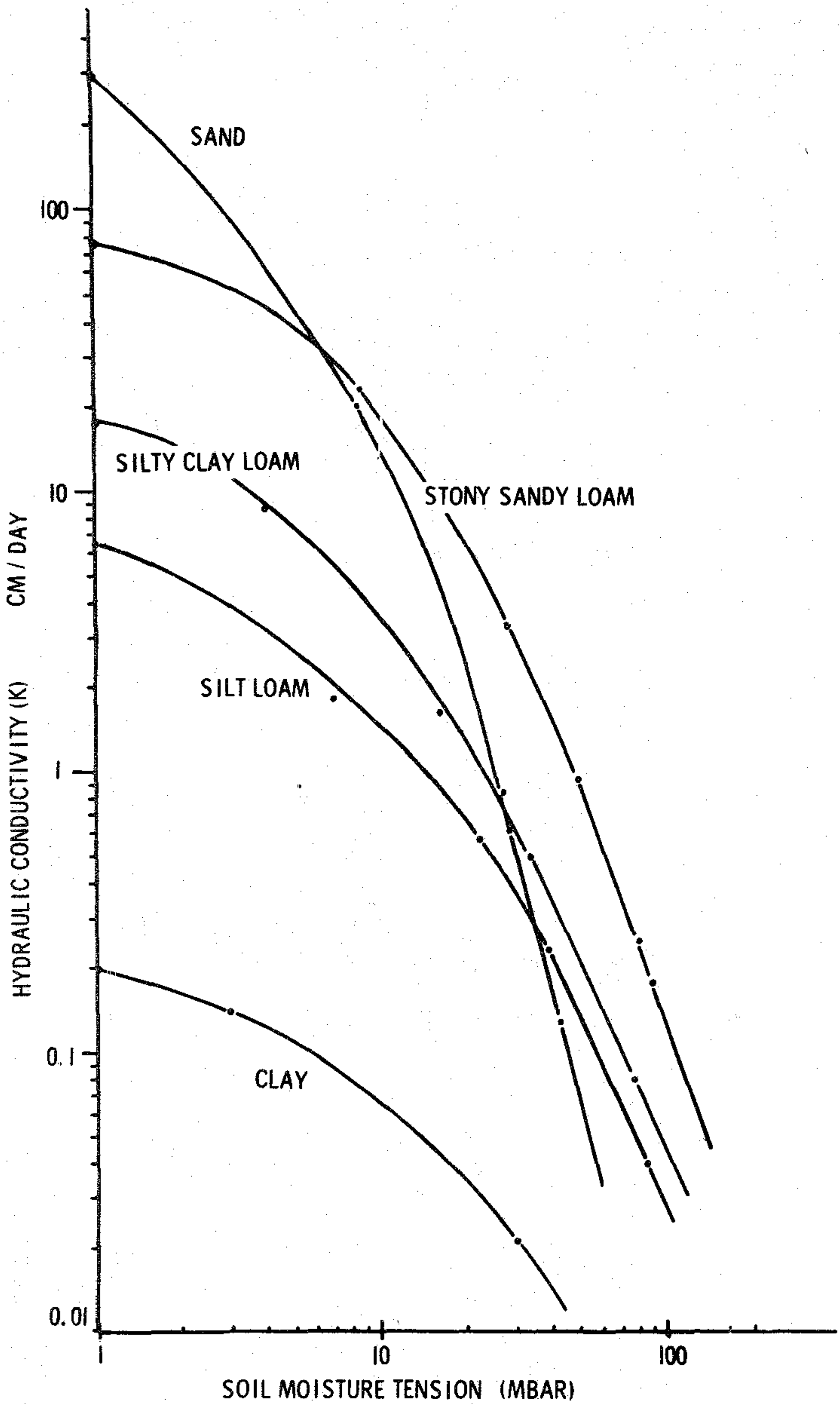


Figure 2.3.4. Hydraulic conductivity (K) versus soil moisture tension relationships for a sand (B3 of Plainfield sand), a stony sandy loam dolomitic glacial till, a silt loam (A2 of Plano silt loam), a silty clay loam (B2 of Plano silt loam) and a clay (B3 of Ontonagon silty clay loam).

into these columns before crusts were added. One column was of glacial till, containing many stones that made use of the Bouwer tubes impossible.

The data indicate that hydraulic conductivity decreases sharply with increasing soil moisture tension. This is most evident in soil materials with coarse pores (B3 Plainfield sand) and less so in fine porous clays (B3 Ontonagon), in which saturated conductivity is low. These results are important for the study of liquid waste disposal in soils. Measurement of soil moisture tensions around seepage beds of operating systems (Section 3) indicated the occurrence of considerable soil moisture tensions. Movement of liquid, therefore, is governed by processes of unsaturated flow. A quantitative analysis of the flow system can only be given when relevant K values, as measured with this new test, are available.

2.4. Soil physical characteristics determined from saran coated clods

2.4.1. Methods

The method to determine soil physical characteristics from large clods, using saran resin as a coating material was introduced by Brasher et al., (1968). Clods should at least have a volume of 100 cm^3, but preferably more than that. They should represent the soil structure from the sampled horizon. In general, about 20 elementary units of structure should be represented in any clod sample. A medium sized blocky structure, with ped volume of 1 cm^3 should be represented by a clod volume of at least 20 cm^3. In coarse prismatic structure this guide does not work, since individual peds may have volumes of 150 cm^3 or more. It should be clearly stated when values are determined for single peds, like these. The method consists of the following stages:

1. A weighed air dry clod is coated with Saran; and slowly saturated with water through one flattened side of the clod where the coating has been temporarily removed.

2. After saturation, the open side of the clod is coated again with Saran and weight and volume of the clod are determined.
3. The coating on the flattened side is removed again, and the clod is placed in a pressure apparatus to determine water contents and soil volume at different pressures. After equilibrium has been reached at a given pressure, the clod is coated again at the flattened side, and weight and volume are determined. It is essential not to loose any soil from the clod during this procedure, since this would lead to erroneous results. After determining moisture contents and volumes of clods for a range of pressures (usually 0.03b, 0.1b, 0.3b, 1b and 15b), the clod is dried at 105°C. Then all values are available to calculate bulk densities, porosities at different suctions, and the moisture retention curve.

2.4.2. Calculation of bulk density values and associated soil physical values from measurements on Saran-coated clods.

Example: Clod from C-horizon of Mexico silt loam, calculations for 1 bar suction only.

Basic data:

Air dry weight of clod: 55.30 gr.

Coated with Saran: 57.90 gr.

Weight of coats: 2.60 gr. = 1.73 cc (Spec. dens. Saran = 1.50)

At 1 bar equilibrium: 57.10 gr.

Volume of clod (+ plastic): 30.50 cc (difference between weight of beaker with water and total weight when clod is suspended in the beaker).

After drying clod + plastic at 105°C for one day: weight = 47.40 gr.

Volume = 27.9 cc.

Calculation 1: Determine bulk density of the soil at 1 bar (bulk density = gr/cm^3 of natural soil). Since B.D. of soil is required, the plastic has to be excluded. Volume of soil at 1 b = 30.50 - 1.73 = 28.77 cc. The weight of 57.10 gr. is composed of water, plastic and soil. After drying at 105°C, weight = 47.40 gr. (= soil + plastic). From a separate experiment it was learned that the Saran plastic looses 25% of its weight when heated for 24 hrs. at 105°C. Soil weight only, therefore, is 47.40 - (0.75 x 2.60) = 45.45 gr. This is an important value, from which bulk densities at different moisture contents are derived. B.D. at 1 bar is: $\frac{45.45}{28.77} = 1.58$.

Calculation 2: Determine percentage of moisture (in % of dry weight and volume) at 1 bar. Stove-dry soil weight was 45.45 gr. We need to know now the weight of the moisture only at 1 bar. Soil + plastic + water = 57.10 gr. Soil + water = 57.10 - 2.60 = 54.50 gr. Moisture % of dry weight = $(\frac{54.50 - 45.45}{45.45}) \times 100\% = 19.9\%$. Moisture % by volume = % of dry weight x B.D. = 19.9 x 1.58 = 31.4%.

Calculation 3: Determine porosity (= vol. % of soil occupied by the non-solid soil phase). Calc. 2 showed that 31.4% of the soil volume is occupied by water at 1 bar suction. What about the remaining 68.6%? For this we need to know one additional soil characteristic: the particle density (= gr/cm^3 of the solid soil phase only). This can be determined by a separate procedure, using pyknometers (see appendix at the end of this section, and Blake, 1965). Presuming we have a particle density of 2.60, the 45.45 gr. of soil represents 17.45 cc. Total volume of clod

Calc. 3 cont.: was 28.77. Pores form 28.77 - 17.45 = 11.29 cc which is 11.29/28.77 x 100% = 39.2% of soil volume. (This means that 7.8% of the pores in the soil are filled with air).

In formula: Porosity = $(1.0 - \frac{\text{Bulk density}}{\text{Particle density}}) \times 100\%$.

Calculation 4: Determine coefficients of linear extensibility (COLE) as $\sqrt[3]{Vm/Vd}-1$, where Vm = volume of moist whole soil fabric and Vd = volume of dry whole soil fabric (Grossman, 1968).

Graphs were prepared for all horizons (for example, Fig. 3.1.3f) showing the moisture retention curve and a curve of total porosity (= upper line). Porosity is sometimes lower at low moisture contents, due to shrinkage.

These calculations were made with the aid of a programmable Hewlett Packard 9100B calculator.

Appendix:

Summary of pyknometer test to determine particle density of soil (see Methods of Soil Analysis).

Pyknometer (dry, empty) = W_1 gr. Pyknometer + about 5 gr. stovedry soil = W_2 gr.

Pyknometer filled with de-aired water = W_3 gr.

Pyknometer with water + soil = W_4.

$$\text{Particle density} = \frac{W_2 - W_1}{W_3 + W_2 - W_1 - W_4} \text{ gr/cm}^3$$

The principle on which the method is based is the same as that for the clod tests: a body suspended in water will be subjected to an upward force that is equal to the weight of the volume of the displaced liquid.

Measurement of soil moisture tension

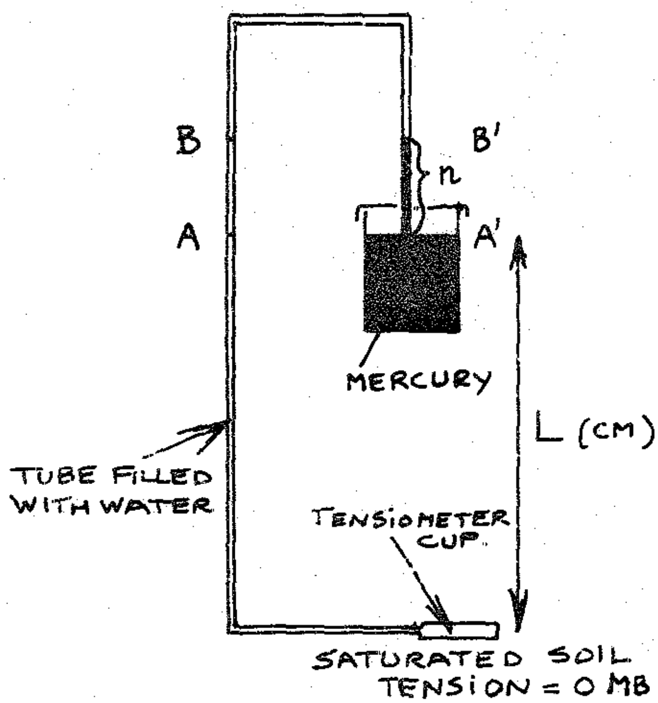


Fig. 2.5

*The authors are indebted to Dr. C. Dirksen for helpful suggestions.

2.5. Tensiometry *

Soil moisture tensions were measured around seepage beds in the field and in columns of the crust test (Sec. 2.3, see Fig. 2.5). General discussions of techniques are given elsewhere (Richards, 1965). We used pencil-sized tensiometers, and 1/8" plastic tubing. A calibrated scale was used to determine soil moisture tension. The procedure of measurement is as follows:

1. Measure distance between the mercury level and the center of the tensiometer, after installation of the cups (= Lcm).
2. Calculate the ratio: $L/12.6$ (cm) = x cm ($\approx$ x mbar).**
3. The zero mark on the scale does not correspond to the mercury level itself, but to a level corresponding to x mbar, above it. Fix the zero of the scale to this level.
4. Readings of total moisture potential (-P mbar) can now be made directly from the scale. Add L to obtain soil moisture tension (= -P+L).
5. The remaining correction results from the negative curvature of the mercury. When the porous tensiometer cup, suspended in water, is held at exactly the level of the mercury, this level and the level in the 1/8" plastic tube do not correspond. Lowering the tensiometer cup 5 cm equalized both levels. This means that each reading has to be corrected with 5 mbar, due to use of the 1/8" tube. The final reading of soil moisture tension is equal to: -P+L-5 mbar.

**Note: the ratio $x = 1/12.6$ is derived as follows: In the pictured system (Fig. 2.5), soil moisture tension is supposed to be zero at the location of the cup. Distance between the mercury level and the tensiometer = L. Mercury has risen in the plastic tube to a height of n cm. The rest of the tube is filled with water. In this equilibrium situation, pressure in the same liquid is similar at the same height. So: Pressure at B = Pressure at B'. However, mercury is present below B' to the mercury level A', and water below B. Considering the flow system as a whole, it follows: $n \times 13.6 - n.1 - L = 0$ and $n = L/12.5 = x$.

2.6. Microbiological procedures. by W. A. Ziebell

2.6.1. Introduction

The general purpose of the bacteriological investigation was to monitor the number of coliform and enterococcus organisms in septic waste and in samples from drainage fields.

Laboratory experiments were also conducted, in which sewage and a suspension, that was bacteriologically representative of the septic tank effluent, were applied to soil columns. The results indicate the nature of bacterial movement from septic systems through soil.

During the summer of 1970 bacterial samples were obtained from five different septic systems. Plating of these to again obtain general microflora, coliform and streptococcus counts was done to get an indication of the movements and densities of bacteria in the field systems.

2.6.2. Materials and methods

2.6.2.1. Techniques of sampling septic systems in the field

Soil samples were taken in the field for bacterial analysis by first sterilizing the exterior layer of soil with a propane torch. A spatula was sterilized with alcohol and used to remove the outer layer of soil. A sterile test tube 1.8 cm diameter by 15 cm was then pushed gently into the soil at the desired sampling point so that the sample entered the tube. Samples for determination of dry weight were also taken adjacent to each bacterial sample and stored in sealed moisture cans. The bacterial samples were transported in an iced container whenever traveling time was to be greater than 30 minutes. This precaution was taken because of known delicacy of enterococci in competition with soil and water flora.

2.6.2.2. Media used and plating techniques

Platings were made for bacteriological analysis from serial dilutions of the sample by a spread plate technique. This is favored over a pour plating technique because in this way all colonies are surface colonies. Thus many interferences in color observations were eliminated and also colonial morphology could be observed.

Total plate counts on plate count agar (PCA) were determined as evidence of total soil microflora. The composition of the agar (PCA) was that given in Standard Methods for the Examination of Water and Waste Water (American Public Health Association, 1965):

tryptone	5 grams
yeast extract	2.5 grams
dextrose	1 gram
agar	15 grams
distilled water	1000 mls

Incubation was at 30°C for 48-72 hrs. For many samples actinomycetes were conspicuous on these plates. They were readily distinguished from the eubacterial colonies by the aerial sporulation of the actinomycetes. Their presence in large numbers is indicative of background soil microflora into which the pollution bacteria are introduced in the vicinity of the drainage system.

Coliforms were enumerated by the test of Standard Methods for the Examination of Water and Waste Water (Am. Publ. Health Ass., 1965) using Levine's Eosin Methylene Blue Agar of the following composition:

peptone	10 grams
lactose	10 grams
dipotassium phosphate	2 grams
agar	15 grams
eosin Y	0.4 grams
methylene blue	0.065 grams
distilled water	1 L

Incubation was at 37°C for 24-48 hours. The total coliform count was recorded for all those bacterial colonies growing on Levine's EMB agar. "Fecal" or

<u>Escherichia coli</u> type organisms were recorded as all those colonies producing a green sheen on Levine's EMB agar. No attempt as yet has been made to use a combination of the two criteria, sheen on EMB and ability to grow at 45°C, as a more reliable indicator of the "facal" coliform population. Experiments on this point are planned.

Streptococcus (presumably <u>S. faecalis</u>) counts were taken on m-Enterococcus Agar of the following composition:

tryptose	20 grams
yeast extract	5 grams
dextrose	2 grams
dipotassium phosphate	4 grams
sodium azide	0.4 grams
agar	10 grams
2,3,5-triphenyl tetrazolium Cl	0.1 grams
distilled water	1 L

After incubation at 37°C for 48-72 hours all red colonies (tetrazolium Cl reducing) were recorded as enterococci.

Other media included were stock agar and nutrient broth for the carrying of cultures of <u>E. coli</u> or isolates of interest. The composition of these was as follows:

Stock agar:

yeast extract	1 gm
dextrose	0.5 gms
distilled water	1 L
agar	15 gms

Nutrient broth:

beef extract	3 gms
peptone	5 gms
distilled water	1 L

2.6.2.3. Techniques for laboratory testing and other experiments

To analyze the field soil, a 10 gram sample of the soil was weighed into a Waring Blender cup and a sterile 90 ml water blank was added. After blending for 1 minute, serial dilutions were made and spread plates of Levine's EMB, PCA and m-Enterococcus agars followed.

Ground water samples from the septic systems sites near Neillsville were analysed by suitable dilution with sterile distilled water blanks and by spread plating onto the three media mentioned in the preceding paragraph.

From the samples and platings made of the septic tank effluents and soil from the drainage area, a number of isolates of apparently significant bacteria types were taken. They are being stored at 4°C on stock agar stants.

Another experiment utilized 200 ml quantities of non-sterilized sewage, heat-sterilized sewage and millipore-filter-sterilized sewage. To these were added the known E. coli ATCC 4348 at 10% inoculum as a liquid culture in nutrient broth. Bacterial counts were then monitored with time.

The following formula was derived to convert the bacterial counts for soil samples to a per gram of dry soil basis:

let $q = \dfrac{\text{number of organisms}}{\text{ml}}$ (after the first addition of diluting water)

(to be determined by plate count)

$$B = \frac{\text{grams of dry soil}}{\text{ml}}$$

then $$A = \frac{\text{number of organisms}}{\text{gram of dry soil}} = \frac{q}{B}$$

then to obtain B we consider

$$P = \frac{\text{\% moisture of soil on dry soil weight basis}}{100}$$

then, if x grams of moist soil are used

$(X-L)P = L$ where L = grams (ml) of moisture in a sample of X grams of moist soil

solving for L gives

$$L = \frac{XP}{1+P}$$

let W = mls of water used in the initial dilution blank

then $B = \dfrac{(X-L)}{(W+L)}$

Photo 3.1 Black sewage sludge (S) flowing from a tile line down the side of an explorato trench across the seepage bed (B-B) at 120-160 cm depth at the Marshfield Expe ment Station. Field tests showed the underlying compact reddish till (T) to be impermeable. Fill (F) above the bed had a bluish "reduced" color and had been enriched in nitrates and organic matter by upwelling effluent.

3.1. Soil absorption system in Withee silt loam at the U.W. Marshfield Agricultural Experiment Station. By D. J. van Rooyen.

3.1.1. Introduction

This system was studied in June, 1970. The septic tank seepage bed was nineteen years old and had been discharging effluent into the road ditch for all but the first 10 to 12 months of its existence. The purpose of this investigation was to study the effects of effluent overflow on the site and to evaluate the potential suitability, if any, of the Withee silt loam for on-site liquid waste disposal.

3.1.2. Soil and landscape features

The Withee silt loam is the most extensive soil in the Withee-Marshfield-Mann* soil association of the region of Grayish-Yellow Silt Loam (Beatty, et al., 1964) (see Figure 3.1.2a). The characteristic landscape position of the Withee silt loam is on the crest and side slopes of upland ridges in undulating terrain. Withee soils (see soil profile description,Appendix 5.1) have a grayish silt loam surface layer which is usually platy. The strongly acid loamy subsoil is dominantly grayish in color, with numerous reddish and yellowish mottles. The lower subsoil has developed in dense reddish-brown loamy glacial till (Beatty, et al., 1964). Water movement down through this soil is extremely slow (Hole, et al., 1967).

The Withee silt loam occurs in two slope phases in the landscape: gently sloping (2-6% slopes) and nearly level (0-2%). All of the investigations were done on the nearly level phase. Fig. 3.1.2b is a soil map of the Marshfield Agricultural Experimental Station.

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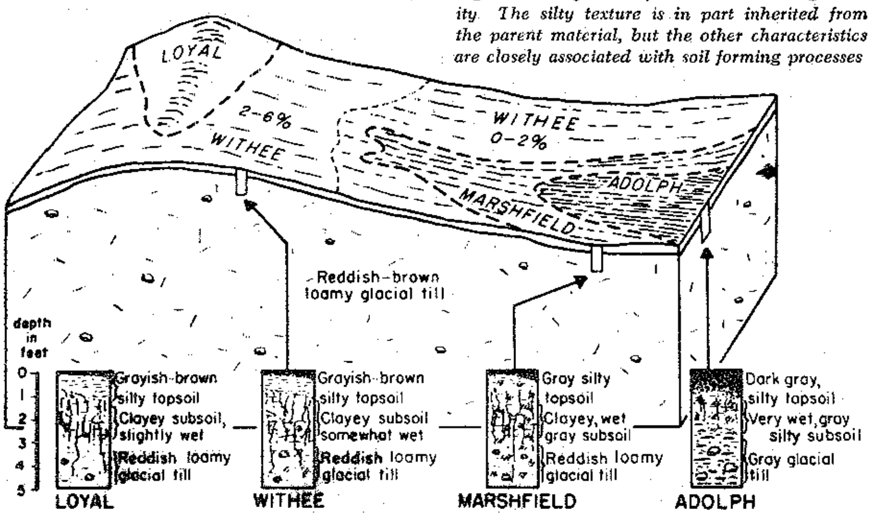
*A new series, The Mann, has been proposed for Adolph-like soils over till that has a texture finer than sandy loam.

Region 4

Diagramatic soil profiles and landscape of the Loyal, Withee, Marshfield, Adolph soil association. The dominant characteristics of soils in this region are silty texture, wetness and strong acidity. The silty texture is in part inherited from the parent material, but the other characteristics are closely associated with soil forming processes



(From Beatty, et al, 1964)

FIG 3.12A

FIG 3.1.2B Soil map of the Marshfield Agricultural Experimental Station, Marshfield, Wisconsin.

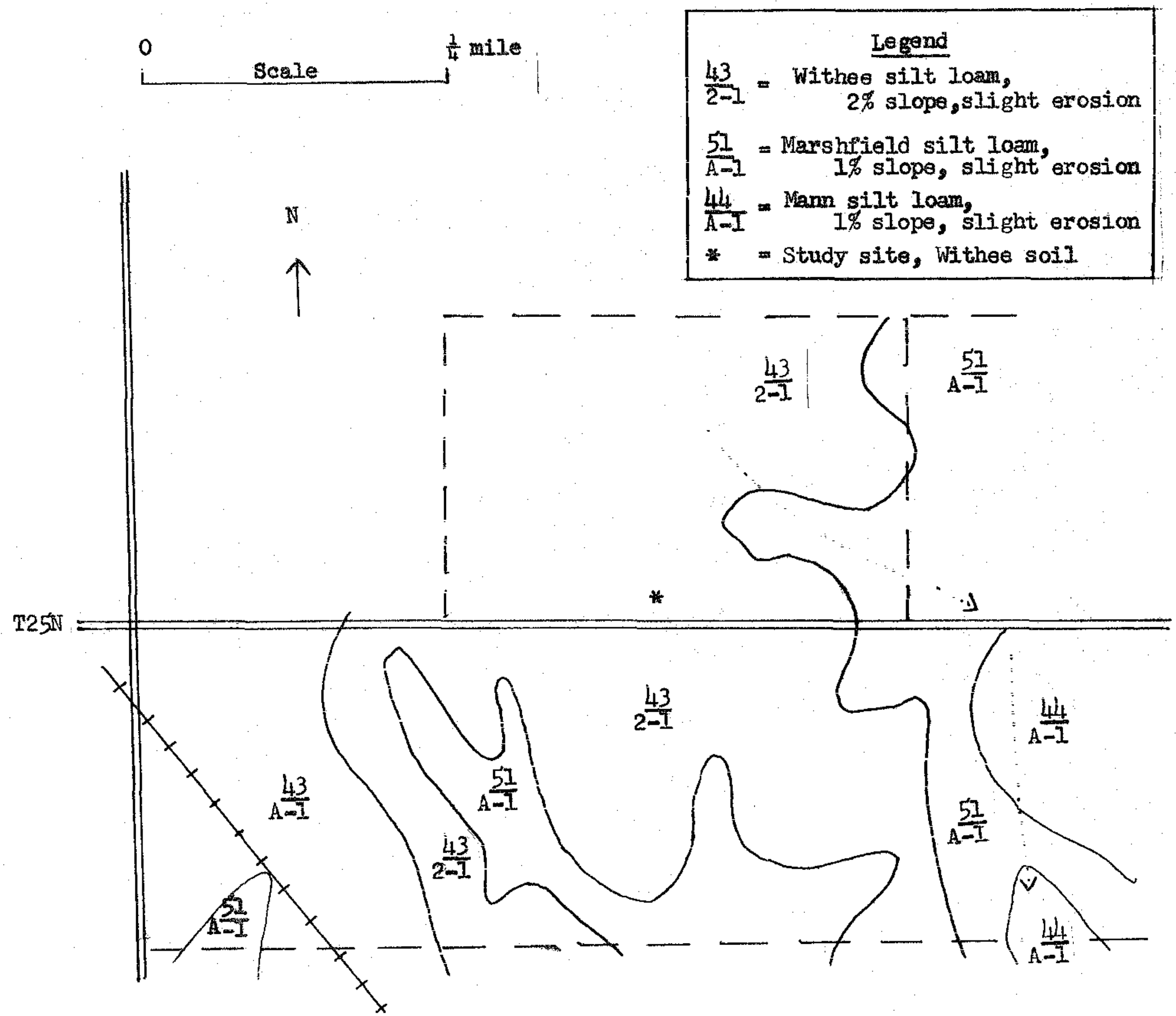
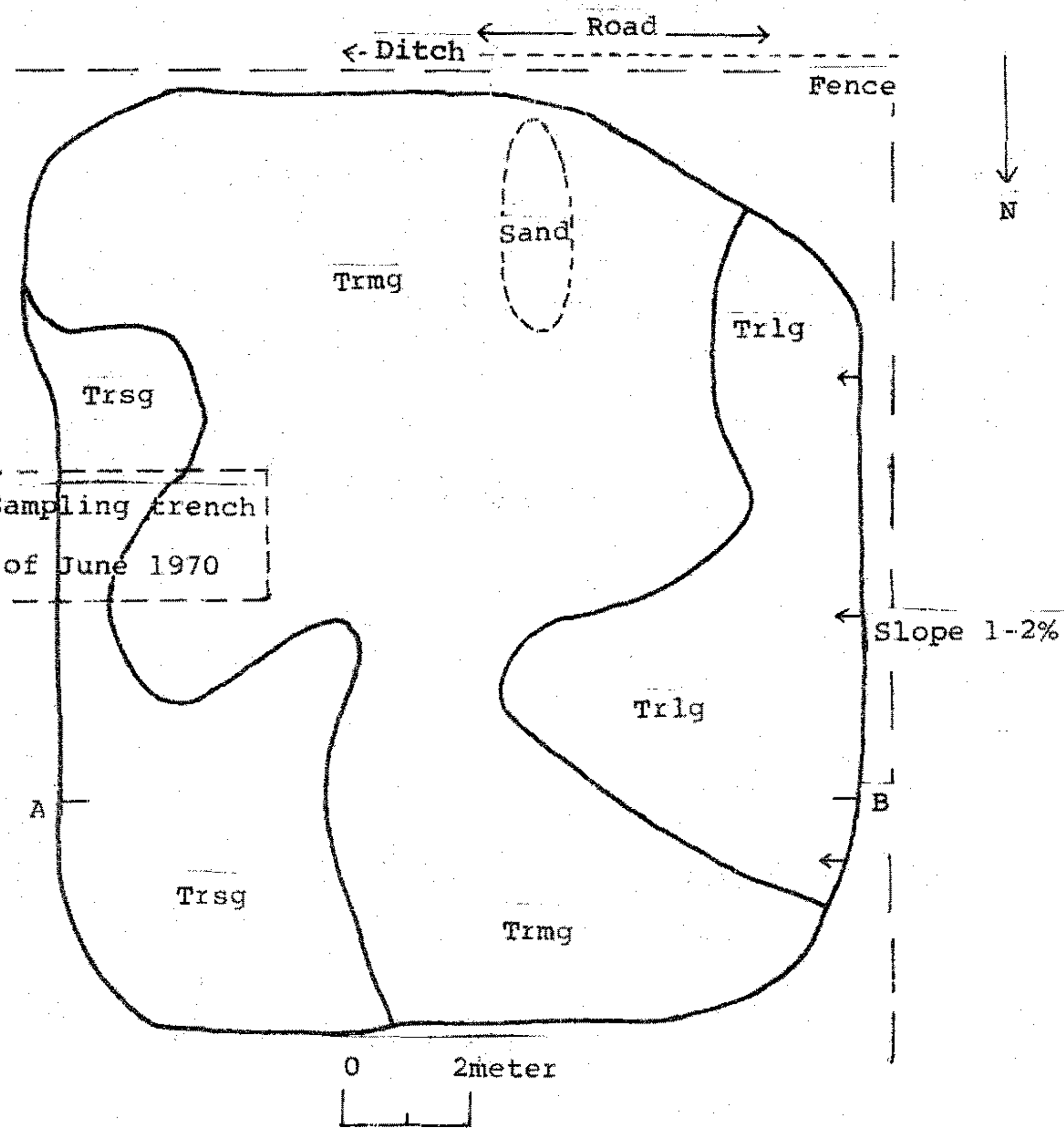


FIG 3.1.3[A] Plan of Seepage Bed



Legend

Tr = Fill material

Severe reduction (0-120cm from surface) = sg
Medium reduction (40-120cm from surface) = mg
Little reduction (80-120cm from surface) = lg

Note: The severe reduced zone is on the left of the seepage system because of the slope in that direction.

Cross-section of seepage bed

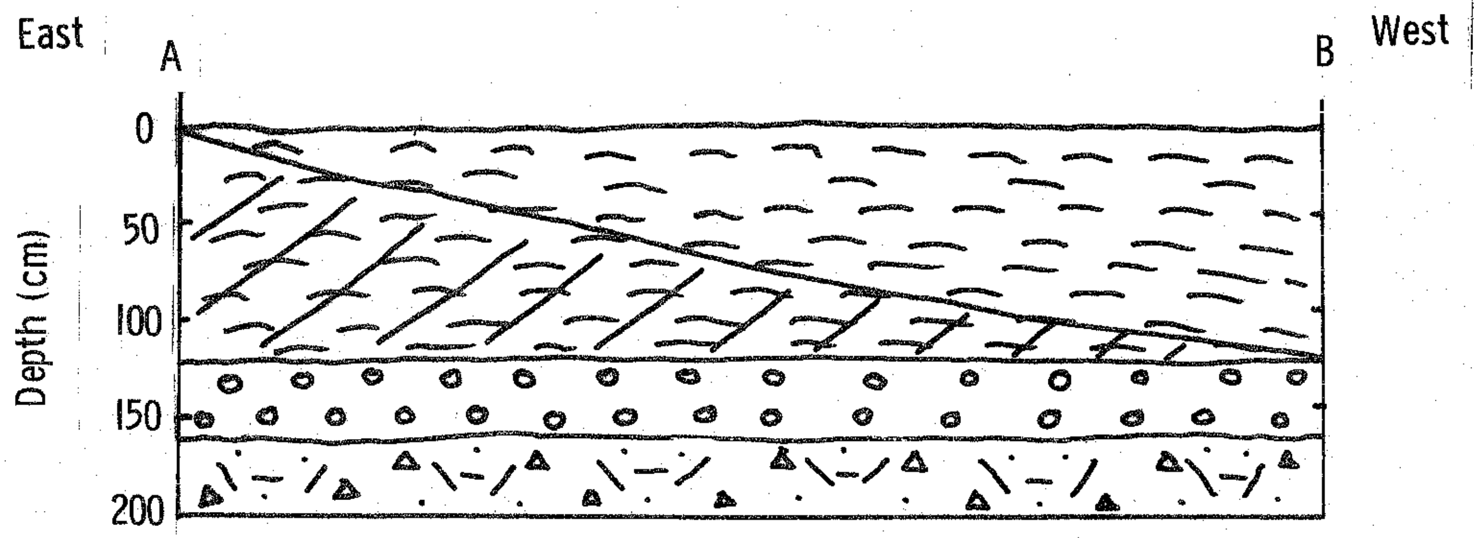


FIG 3.1.3[8]

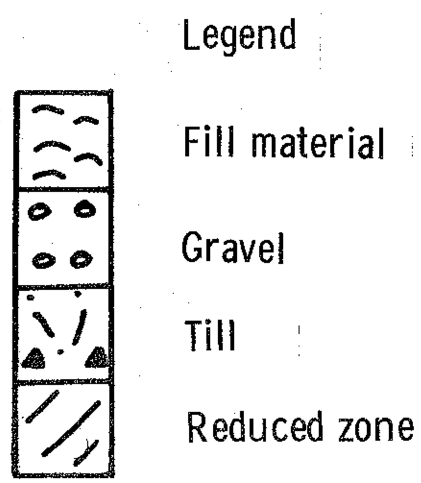


FIG 3.13c Index map showing location of the east seepage field of the Marshfield Experimental Station and sampling sites.

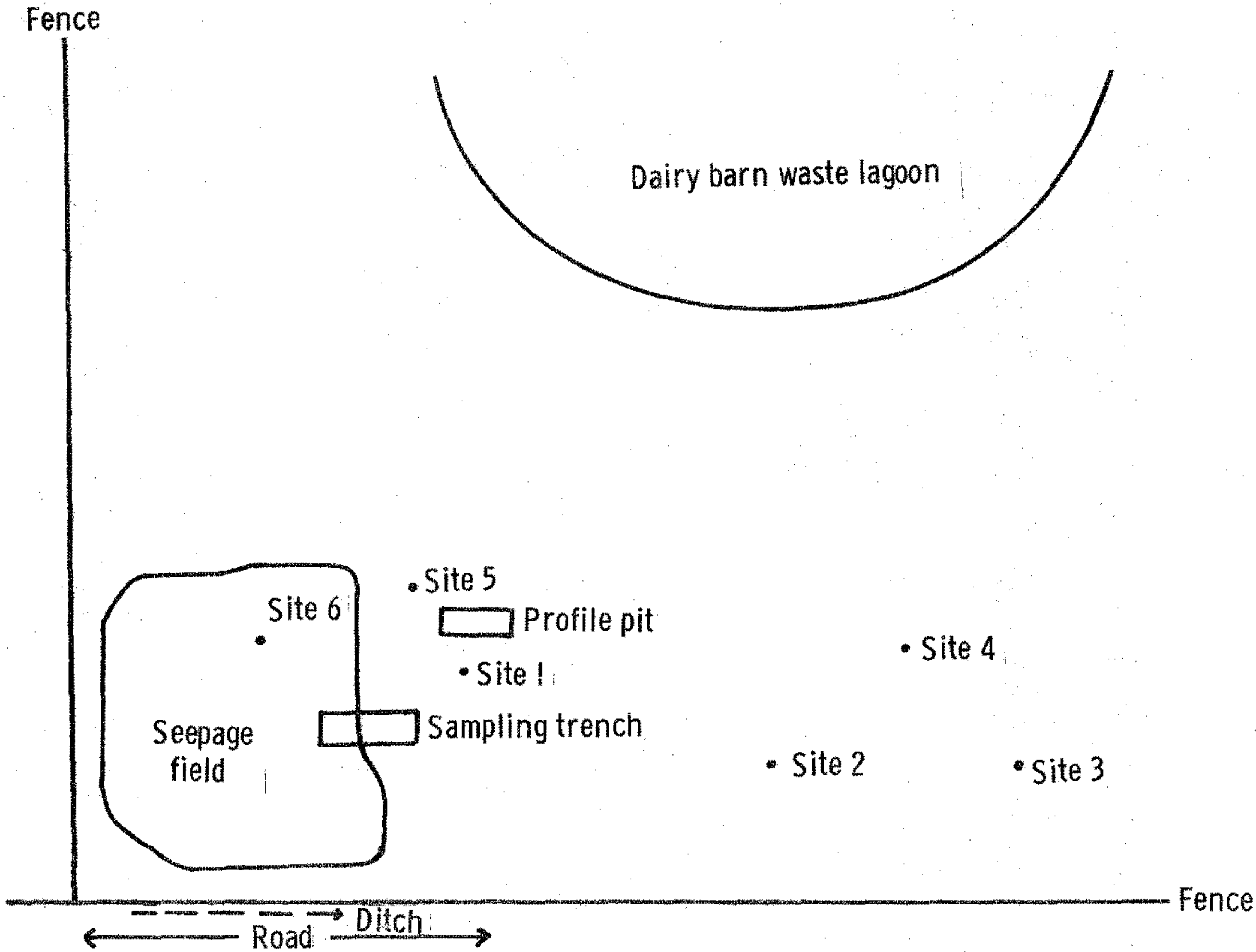


Table 3.1.3.3. Color Readings[1/] above and below gravel seepage bed. Marshfield Agricultural Experiment Farm. June, 1970.

Depth	Material	Colors	Depth	Material	Colors
40	Fill	7.5Y 4/1+ Olive black	150-153	Undisturbed soil material	5YR 3/6+ Dark reddish brown in sand fraction
60		7.5Y 5/1+ Gray	153-163		5YR 4/6* Yellowish red in heavy clay
80		7.5Y 5/1+ Gray	163-183		10YR 4/6+ Brown in heavy clay
100		10Y 4/1+ Gray	183-213		7.5YR 4/4* Dark brown in heavy clay
115		10Y 4/1+ Dark greenish gray			
120-150	Gravel bed				

1/The colors indicate no reduction below the gravel bed which in turn indicates no sufficient downward movement of effluent to create an environment of reduction as is found above the gravel bed.

* Munsell color designations are for moist soil unless stated otherwise.

\+ Color and notation from the Japanese Standard Soil Color Chart.

Table 3.1.3.4. Hydraulic conductivity (K in cm/day)+ and percolation test results of Withee silt loam, Marshfield Agr. Exp. Sta.

Depths (cm)	Site 1*	Site 2*	Site 3*	Date of Observation
20	0	---	---	June 5
25	---	---	10	June 10
40	0	0	2	June 10
70	0	---	---	June 3
80	0	---	---	June 2
State Percolation Test (80 cm)			2800 min/inch	June 10

\+Data taken by means of the Bouwer Double Tube Method.

*See Figure 1.3.1c for locations.

Table 3.1.3.1 Moisture content (%)+ of soil samples from a cultivated Withee silt loam and soil fill of a disposal field# at the Marshfield Agricultural Experiment Station.

Depth (cm)	Withee Silt Loam Site 5*	Disposal Field Site 6* (Trmg**)
20	19.7	27.7
40	15.7	17.7
60	14.5	17.2
80	18.5	19.9
100	18.8	20.3
120	13.6	36.0
140	19.4	31.7

\+Based on stove dry weight of soil.

\#This disposal field is part of a septic system installed in 1951.

*See Figure 3.1.3c for locations.

**Soil map unit, Figure 3.1.3a.

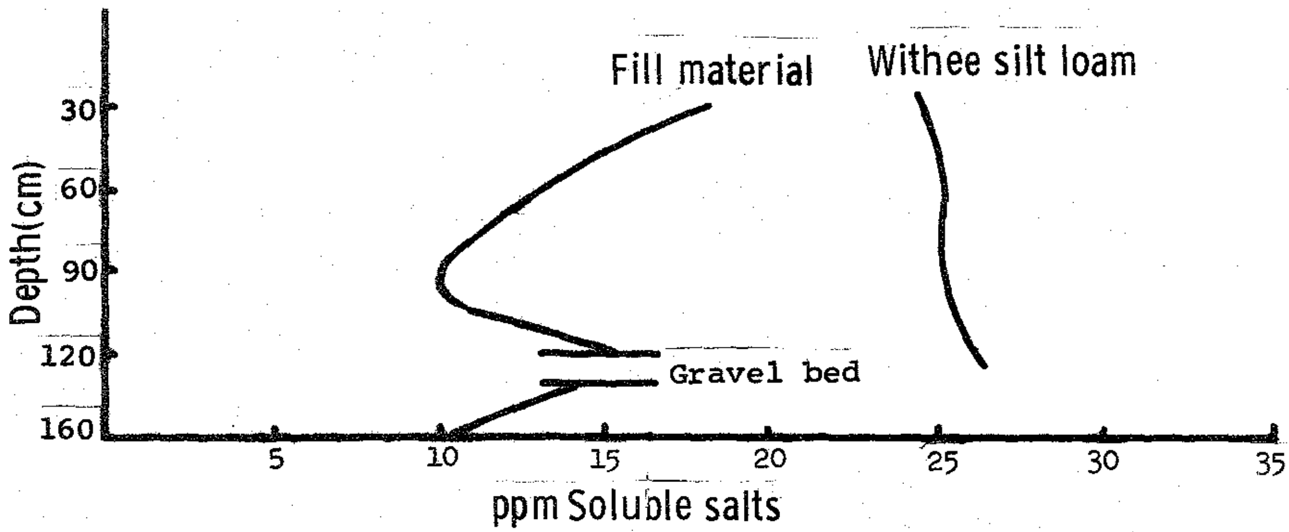
Table 3.1.3.2 ANALYSES* OF FERTILITY SAMPLES TAKEN AT THE MARSHFIELD AGRICULTURAL EXPERIMENTAL STATION, COLLEGE OF AGRICULTURAL AND LIFE SCIENCES, UNIVERSITY OF WISCONSIN, MARSHFIELD, WISCONSIN, JUNE, 1970.(fill in map unit Trmg, Fig. 3.1.3a)

SITE	SAMPLE	(cm) DEPTH	pH	%OM	P	K	Ca (pp2m)	Mg	Sa	ppm NO_3	TOTAL N %
Disposal Field	Fill material	30	7.0	2.8	73	810	150	80	20	<10	0.191
			6.25	1.6	45.5	1050	140	90	18	<10	0.118
		30	5.5	0.4	18	1290	130	100	16	<10	0.045
		60	5.7	0.7	28	220	120	60	16	<10	0.045
			5.6	0.7	28	202.5	125	65	13	12.5	0.045
		60	5.5	0.7	28	185	130	70	10	15	0.045
		90	6.0	0.7	46	160	180	100	10	80	0.039
			6.25	0.5	39.5	162.5	196	105	10	47.5	0.035
		90	6.5	0.3	33	165	200	110	10	15	0.031
		120	6.8	0.3	50	365	220	100	16	60	0.045
			6.65	0.35	37.5	320	205	100	16	35	0.044
		120	6.5	0.4	25	275	190	100	16	<10	0.042
	Till Beneath gravel bed	160	6.7	0.2	63	200	180	110	10	<10	0.034
			6.25	0.2	59	205	180	110	10	<10	0.034
		160	5.8	0.2	55	210	180	110	10	<10	0.034
	Cultivated Withee silt loam	30	4.2	0.3	28	600	120	120	23	45	0.025
			4.35	0.35	66.5	600	165	102.5	24	25.5	0.030
		30	4.5	0.4	105	600	170	85	25	<10	0.034
		60	4.2	0.3	23	175	160	110	28	<10	0.017
			4.2	0.25	43	177.5	165~~0~~	105	25.5	<10	0.016
		60	4.2	0.2	63	180	170	100	23	<10	0.014
		90	4.2	0.1	32	120	130	125	20	<10	0.008
			4.15	0.15	35	135	155	125	25	<10	0.013
		90	4.1	0.2	38	150	180	125	30	<10	0.017
		120	4.3	0.1	73	150	180	110	30	<10	0.034
			4.3	0.1	53	152.5	195	120	27.5	<10	0.034
		120	4.3	0.1	33	155	210	130	25	<10	0.034

*Analyses by the Soil Testing Laboratory, Department of Soil Science, Marshfield Agricultural Experimental Station.

Graphs showing distribution of soluble salts and nitrates in seepage field fill material and the undisturbed Withee silt loam

Soluble salts content



Nitrate content

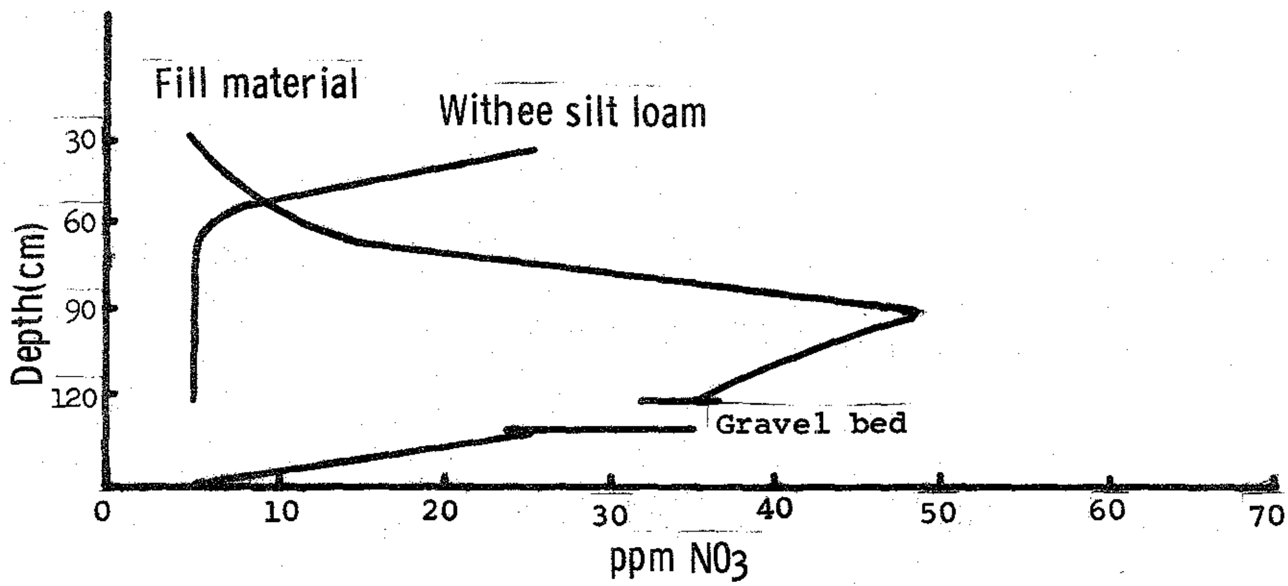
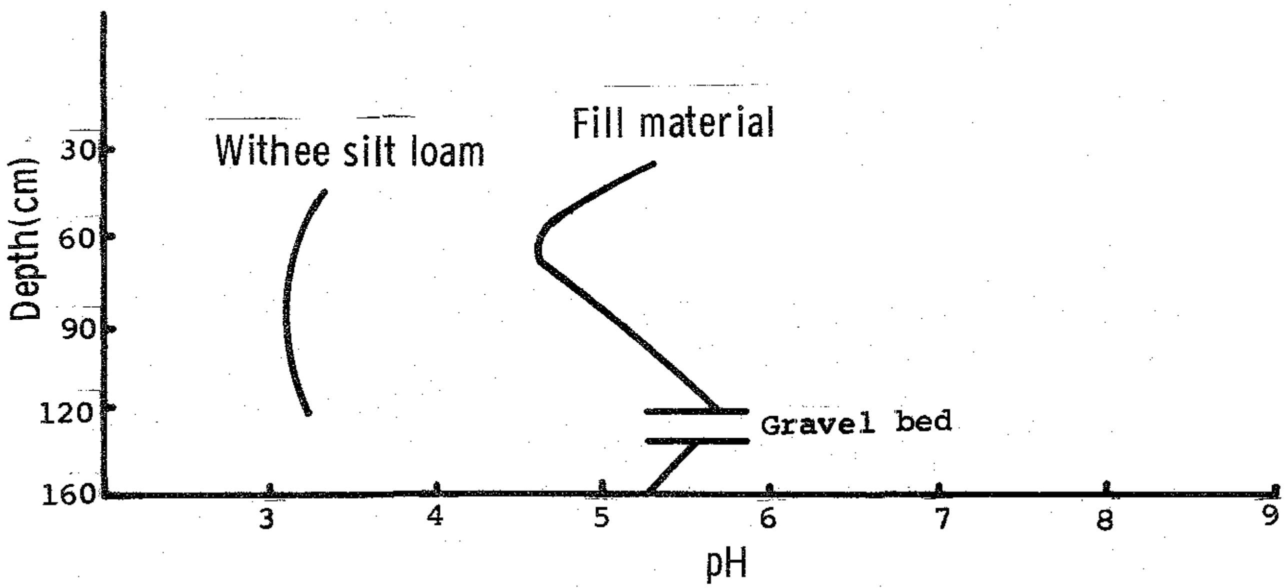


FIG 3.1 3 D

Graphs showing distribution of soil reaction variations and organic matter content in the seepage bed fill material and undisturbed Withee silt loam

Soil reaction



Organic matter content

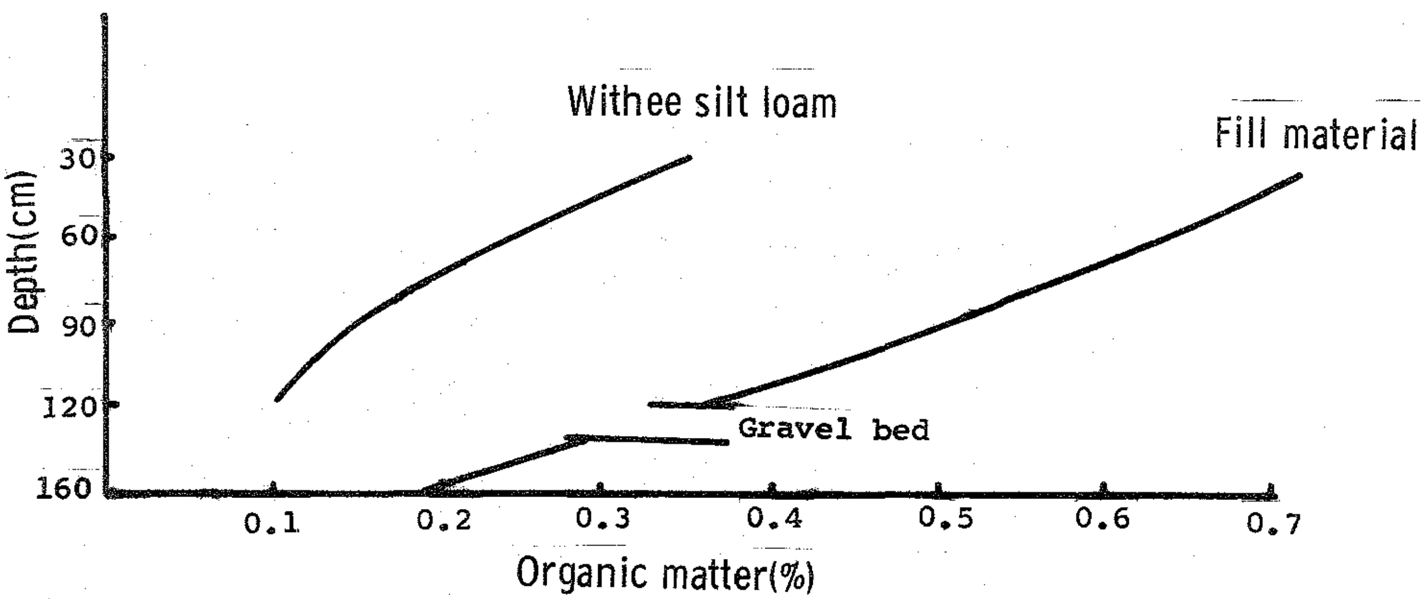
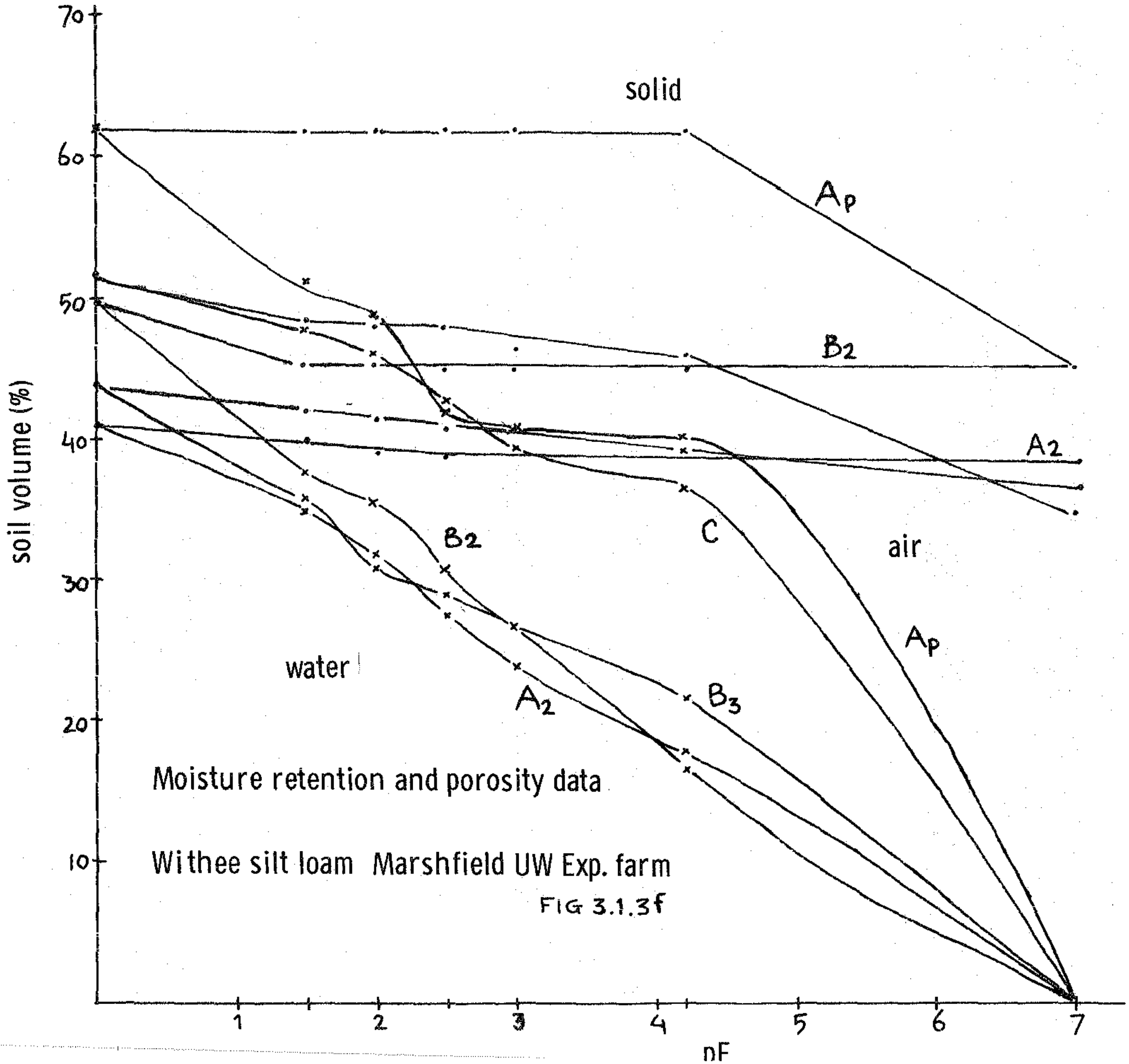


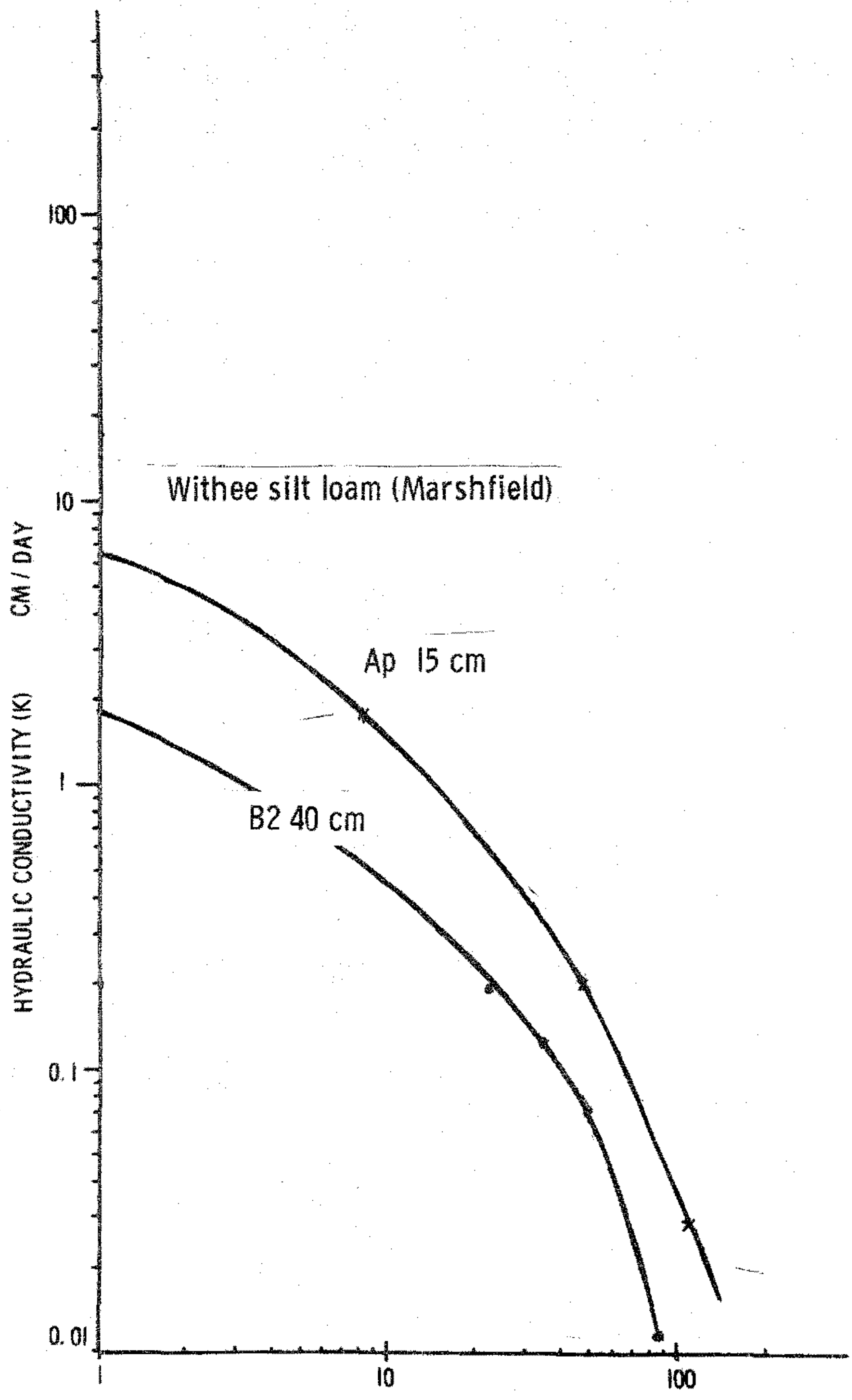
FIG 3.13e



Moisture retention and porosity data

Withee silt loam Marshfield UW Exp. farm

FIG 3.1.3f



Withee silt loam (Marshfield)
Ap 15 cm
B2 40 cm
100
10
1
0.1
0.01
HYDRAULIC CONDUCTIVITY (K) CM / DAY
1
10
100
SOIL MOISTURE TENSION (MBAR)

FIG. 3.13G

3.1.3. Results

The extent of the tile field was determined by auger borings at two-meter intervals on a grid pattern (Fig. 3.1.3a). From this map a section was drawn in order to indicate the positions of the reduced zones in the fill above the gravel bed (Fig. 3.1.3b). A general map of the immediate surroundings is presented in Fig. 3.1.3c.

Samples for fertility and moisture determinations were taken at several sites and at different depths on, around and beneath the gravel bed of the tile field. Samples were taken by means of an auger. Results of analyses of these samples are shown in Table 3.1.3.1 (soil moisture data) and Table 3.1.3.2 (soil fertility data). Figures 3.1.3d and 3.1.3e show these contents as a function of depth.

Colors of the fill material above the gravel bed and the soil beneath it (Table 3.1.3.3) can be compared with colors of a near-by soil profile (Appendix 6.1). Hydraulic characteristics of the Withee soil are reported as moisture retention data (Fig. 3.1.3f), results from the crust tests in the Ap and B2 horizons (Fig. 3.1.3g) and hydraulic conductivity of saturated soil by the Bouwer method and percolation test results (Table 3.1.3.4).

3.1.4. Discussion

The Withee silt loam has long proved itself incapable of accepting and treating liquid wastes below ground.

The malfunctioning of this particular disposal system was confirmed by the study. There was no color change or morphological evidence to indicate downward or sideward movement of effluent from the seepage bed. Hydraulic conductivity, as measured by the Bouwer-double tube method, was so low as to be immeasurable at depths of 50 cm or more. Hydraulic conductivity values of 10 cm and 2 cm per day were found at 25 cm and 40 cm depths, respectively.

The State Percolation Test indicated very slow infiltration at a depth of 80 cm. Inclement weather prevented completion of the crust test at a depth of 80 cm in the B3 horizon. Results indicated that K at saturation was less than 2 mm/day. Physical measurements, therefore, confirm the morphological evidence.

The natural soil was relatively wet in June, 1970 and it can be hypothesized that the swollen state of the soil system in June contributed to the low K values, because the cracks were closed. However, additional measurements in August proved that saturated hydraulic conductivity for initially unsaturated soil was also negligibly small. Such slow movement of water as does occur in the subsoil seems to take place mainly along cracks, as indicated by skeletans on their surfaces (see profile description). Moisture contents of the fill above the gravel bed were higher throughout than at comparable depths in the natural soil profile adjacent to the gravel bed. Whereas the unsaturated natural soil material was firm in consistence, the reduced fill material, saturated by the upwelling stream of effluent, was plastic and sticky. The effluent was apparently confined to the fill judging by the sharp boundary between the bluish gray fill material and the browner surrounding soil.

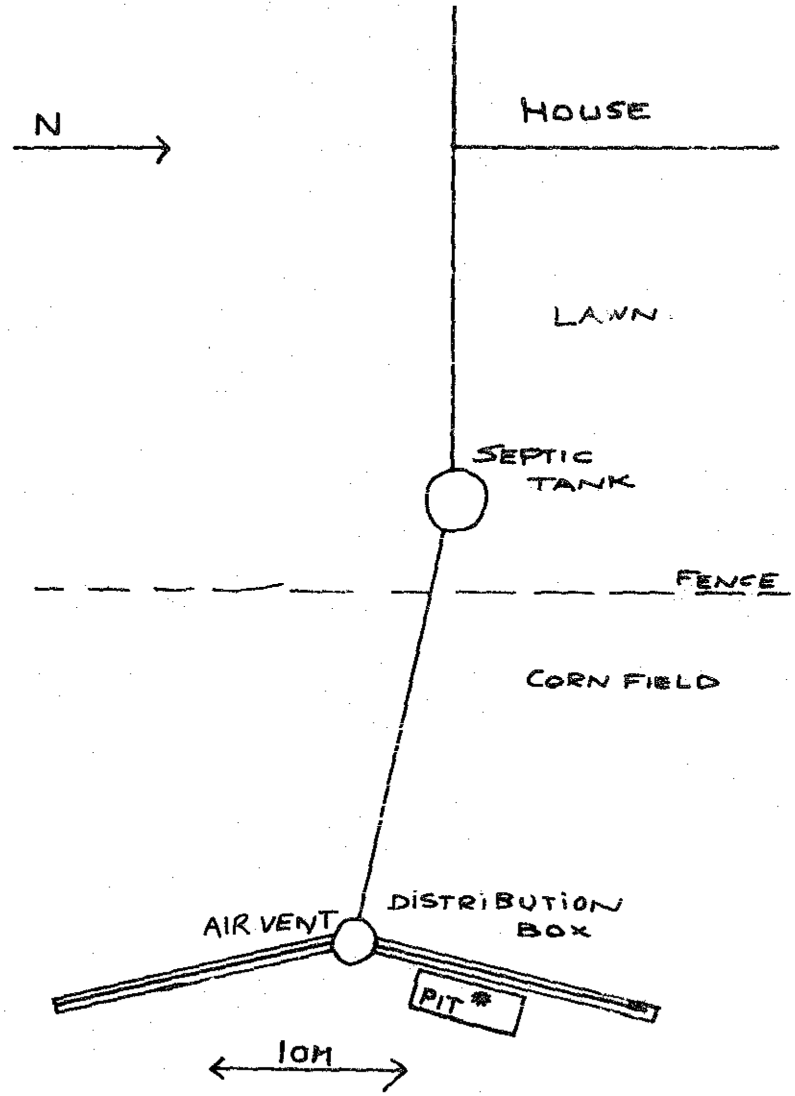
Soil reaction, and contents of organic matter and nitrates are higher in the fill than in the natural soil, as a result of enrichment by upwelling effluent in the fill. Addition of fertilizers to the topsoil in regular farm operations in adjacent soil areas accounts for the concentrations of nitrates and soluble salts in the Ap horizon of the Withee soil.

The moisture retention curves (Fig. 3.1.3f) show that the Ap horizon has a high content of water at saturation. As soil moisture tension increases, larger pores are emptied rapidly. The Ap has a larger water holding capacity, resulting from a higher porosity, than the underlying compacted A2, the B2 and B3 horizon. The decrease in content of soil moisture with increasing tension is least in the A2 and B horizons due to the relatively large volume of fine pores in them.

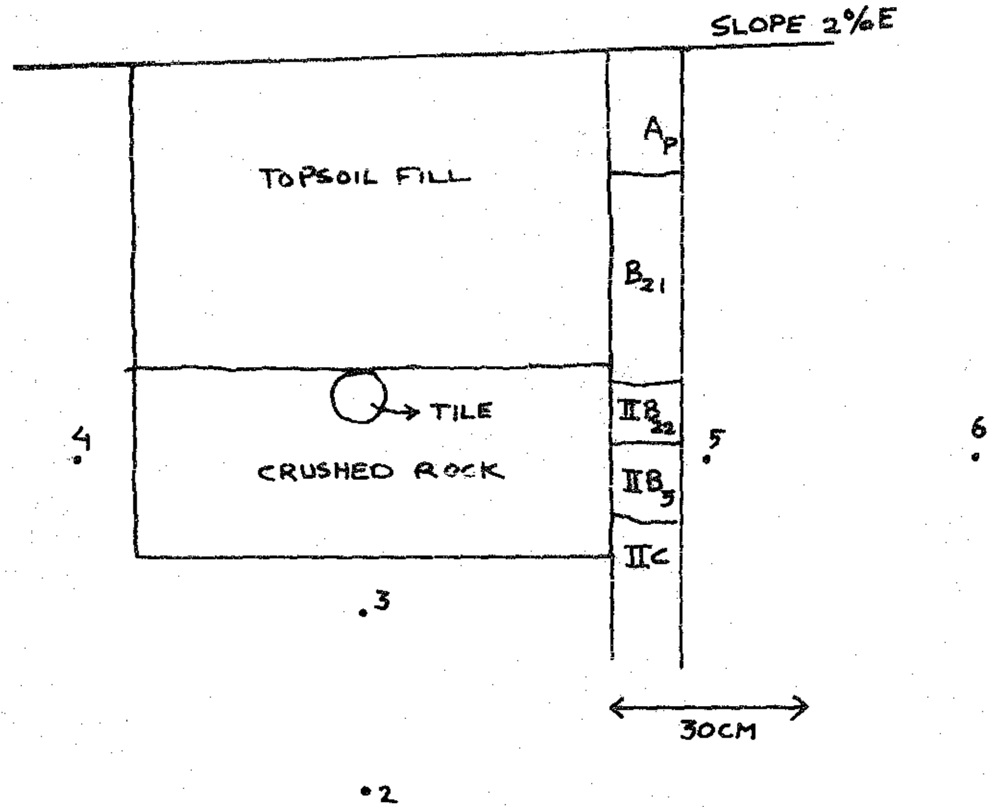
At high suctions the A2 horizon has a lower moisture content than the B3 and C horizons. This is because the A2 horizon has less clay to bind the water.

In conclusion, the septic tank disposal field as described herein does not function because liquids cannot percolate through the soil and hence are forced to the surface. The field acts as a surface-leaking storage tank instead of a disposal field. All this indicates that the Withee silt loam cannot dispose of liquid wastes sufficiently to service the conventional seepage bed and that a system of different design is needed, utilizing, if possible, the conductivity and storage capacity of the upper 40 cm of the profile. A properly constructed "mound" system might meet the need. Potential capabilities of "mound" systems, designed for sites with hydraulic conditions like those of the Whitee silt loam, are discussed in Section 3.6.

SOIL ABSORPTION SYSTEM IN STONY SANDY LOAM TILL (Poultry farm, Arlington)



Top view of seepage bed



Cross section of trench with locations of tensiometers

Fig. 3.2.1.

3.2. Soil absorption system in stony sandy loam till (II C horizon of the Saybrook silt loam at the Poultry and Dairy Farms, U.W., Arlington, Agric. Exper. Sta.)

3.2.1. Introduction

The system at the Dairy farm was briefly studied in July, 1970 and found to be similar in design and dimensions as the system at the Poultry Farm (Fig. 3.2.1). This system was overloaded at a loading rate of 350 gallons/day, as was evidenced by periodic overflow of effluent through the air vent on top of the distribution box. Abundant growth of grasses and weeds downslope from this point, demonstrated the effect of this added fertility. A deep pit was dug next to the seepage bed. Unfortunately, one sidewall of the pit caved in, and the hole filled with effluent. The site had to be abandoned after this abrupt change in hydraulic conditions. The septic tank disposal system at the Poultry Farm (Fig. 3.2.1) was loaded at the much lower rate of 80 gallons per day and had worked satisfactorily for eleven years. A large pit was dug next to one of the two seepage trenches and a tunnel extended under the trench (see Fig. 3.2.1). Tensiometers were installed on July 20 at several distances below and at the sides of the trench. Stoniness of the till was not such as to prevent installation of the tensiometers, although several attempts were necessary at most points before success was attained. Soil moisture tension measurements began as soon as equilibrium had been reached on July 21. The topsoil fill was removed from above the far end of the seepage trench and the depth of effluent found to be 20 cm. In order to study effects of dosing the access was closed at the distribution box,the effluent was pumped out and the trench was left empty of liquid from July 22 to August 4, 1970 . During this period the other seepage trench and surrounding soil handled all the effluent of the system. The effluent was admitted to the north trench on Aug. 4, and the amount of liquid introduced into the entire system was increased to an average 200 gallons per day, starting on August 8, by running water from a

Soil moisture tensions around seepage bed in stony till (Arlington)

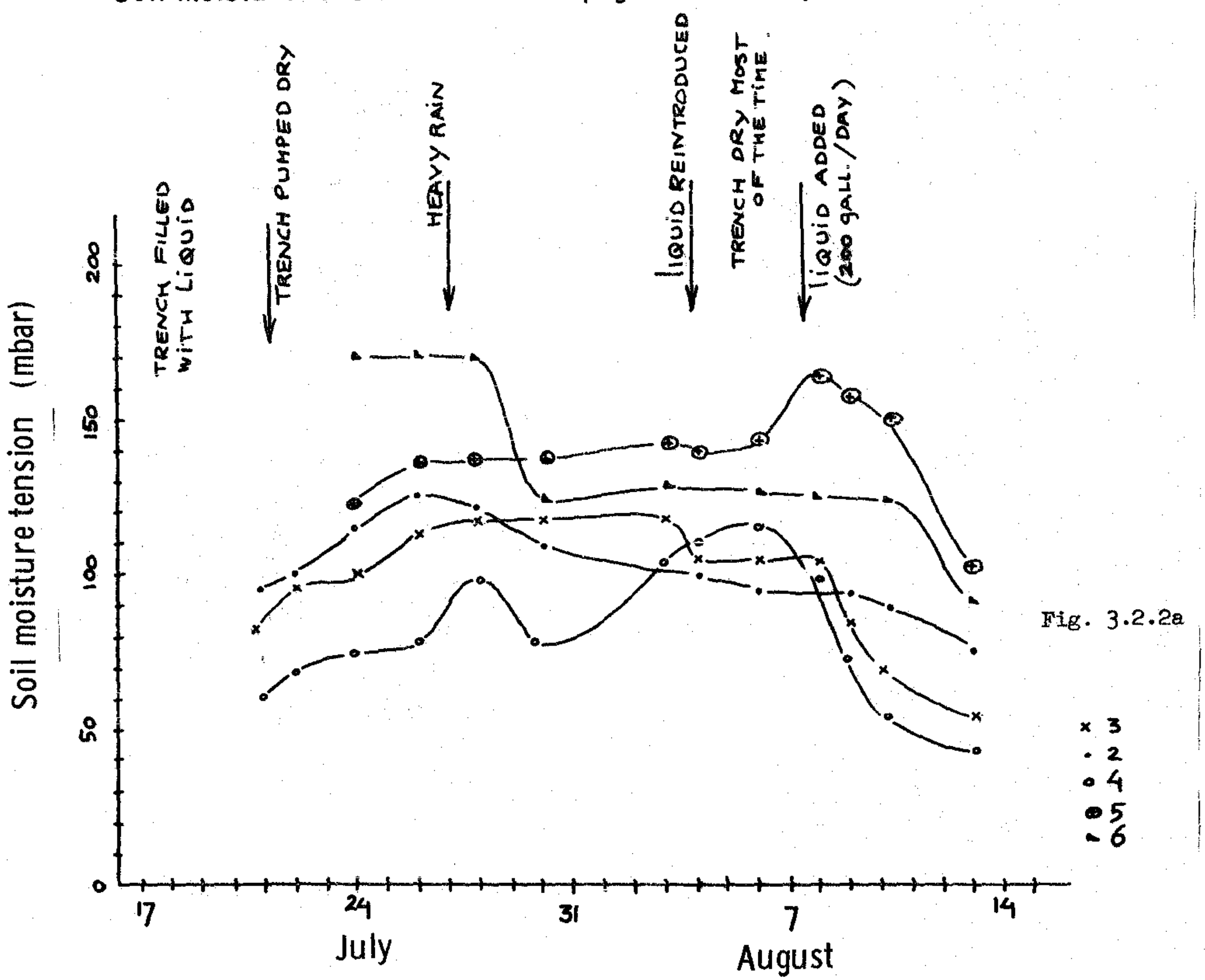


Fig. 3.2.2a

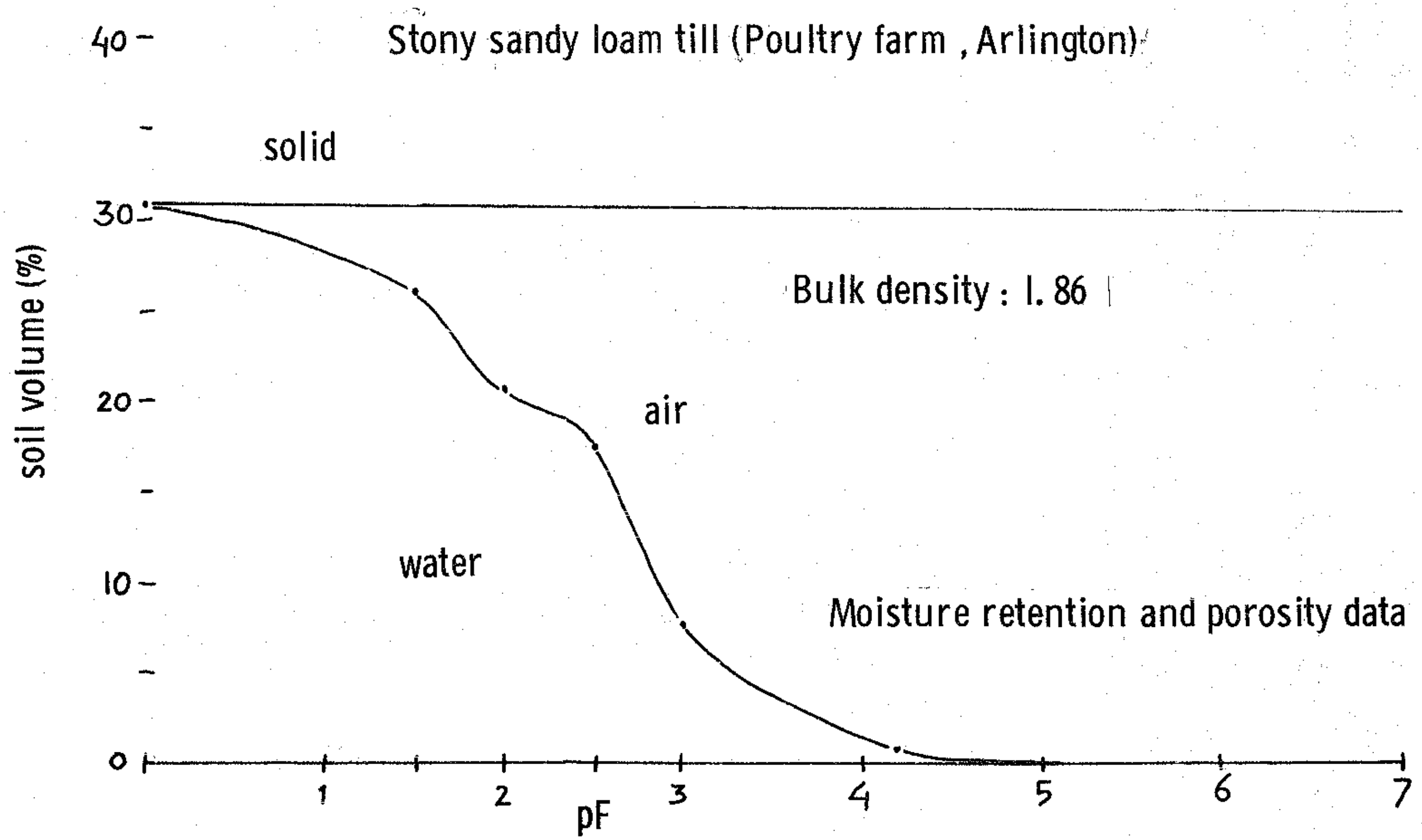

Stony sandy loam till (Poultry farm , Arlington)
40
30
20
10
0
soil volume (%)
solid
Bulk density : 1.86
air
water
Moisture retention and porosity data
1
2
3
4
5
6
7
pF

Fig. 3.2.2b

faucet in the basement of the house. This part of the experiments was finished on August 14 (Fig. 3.2.2a). A second series of experiments was started on September 18 (Fig. 3.2.2d). The occupants of the house had been on holidays for a three week period from August 14 to September 4. No effluent was in the trench at the start of the second experimental period. Large amounts of water were added to the system for short periods of time on certain days (Fig. 3.2.2a). Tensiometric reactions to these intermittent dosages were observed. From October 1 to October 7, a continuous trickle of water was added by means of the basement faucet to establish a total rate of 200 gallons per day. After October 7, only the regular input of 80 gallons per day entered the system. The experiment was terminated on October 15.

3.2.2. Results

Moisture retention and porosity data for the glacial till are presented in Figure 3.2.2b, and data of the crust test, relating hydraulic conductivity to soil moisture tension, are shown in Fig. 3.2.2d. Six state percolation tests (Fig. 3.5.2.13) and two constant level percolation tests (see Fig. 3.5.2.23) were made in the till at the Dairy and Poultry Farms. Soil moisture tensions, as measured around the trenches during the experiments, are presented in Figures 3.2.2a and 3.2.2c. Results of microbiological analyses of samples taken at the locations of the tensiometers at two times are in Tables 3.2.2.1 and 3.2.2.2.

3.2.3. Discussion

Soil moisture tensions were high around the seepage trench at the start of the experiment on July 21, although the level of the effluent stood at two-thirds the height of the bed of crushed rock. Below the trench tension was 80 mb (Tensiometer nr. 3) and 90 mb (Tensiometer nr. 2). At the sides, the value was somewhat lower at 60 mb. The presence of such high tensions, and free liquid in the trench, indicates the presence of a highly resistant barrier,

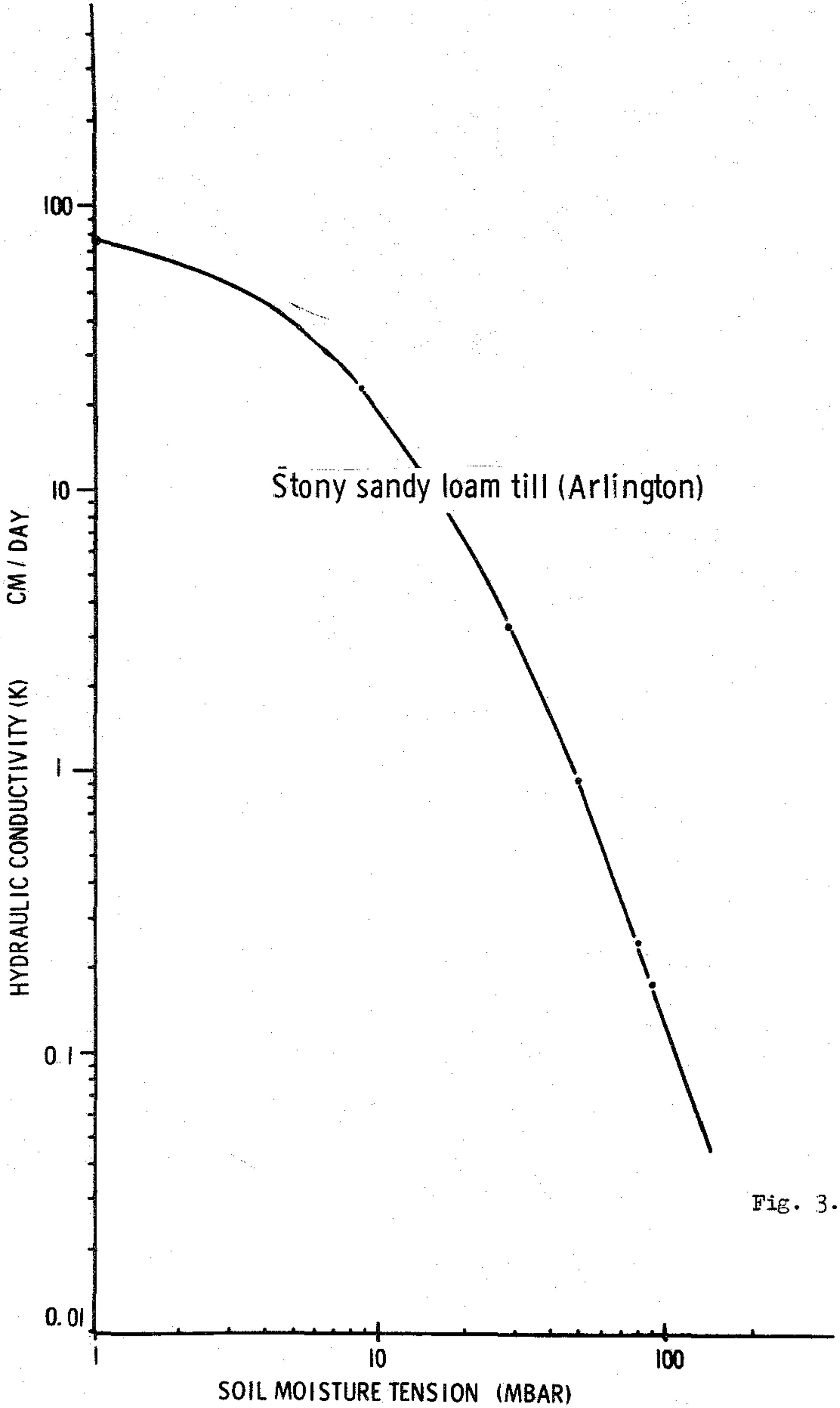

100
10
1
0.1
0.01
HYDRAULIC CONDUCTIVITY (K) CM / DAY
Stony sandy loam till (Arlington)
1
10
100
SOIL MOISTURE TENSION (MBAR)

Fig. 3.2.2c

a "crust", at the interface between trench and soil, causing a potential head loss (Hillel and Gardner, 1970) (see also Section 3.2.5).

Soil moisture tensions increased by natural drainage, as expected, after the trench was pumped dry on July 22. Heavy rain on July 28 decreased most tensions, but at the time of reintroduction of the effluent in the system on August 4 tensions were still considerably higher than those at the start of the experiment. In the period from August 4 to 8, tensions did not change. At no time did we observe effluent standing in the trench. Obviously, the amount of effluent going into the system (80 gallons/day) was being absorbed by the soil, without ponding. Moisture tensions around the trench probably fluctuated each day, following the daily dosing pattern. Since observations were made only once a day such effects were not observed. An attempt was made to reëstablish ponding in the trench, by increasing the loading rate to 200 gallons per day. A permanent trickle of water into the system from a faucet in the basement of the house was sufficient to accomplish this. The much increased loading rate apparently exceeded the infiltrative capacity of the soil, and effluent filled the trench again starting August 8 and remained so until the end of the first experiment on August 14. Soil moisture tensions decreased to values of 50 mb below, and 35 mb next to the trench. This indicates a marked decrease in impedance by the crust, as compared with that under the initial condition, when the trench was nearly full of effluent and much higher tensions obtained in the surrounding soil.

Fig. 3.2.2c gives the relationship between hydraulic conductivity K and soil moisture tension for the sandy till. K at 70 mb was 4 mm/day, at 50 mb: 15 mm/day. For a bottom area of 0.8 x 30 = 24 m^2, this would amount to a vertical (one dimensional) flow of 50 gallons/day at 80 mb (potential gradient = 2) and 180 gallons/day at 50 mb (potential gradient = 2). For the bottom of one trench,

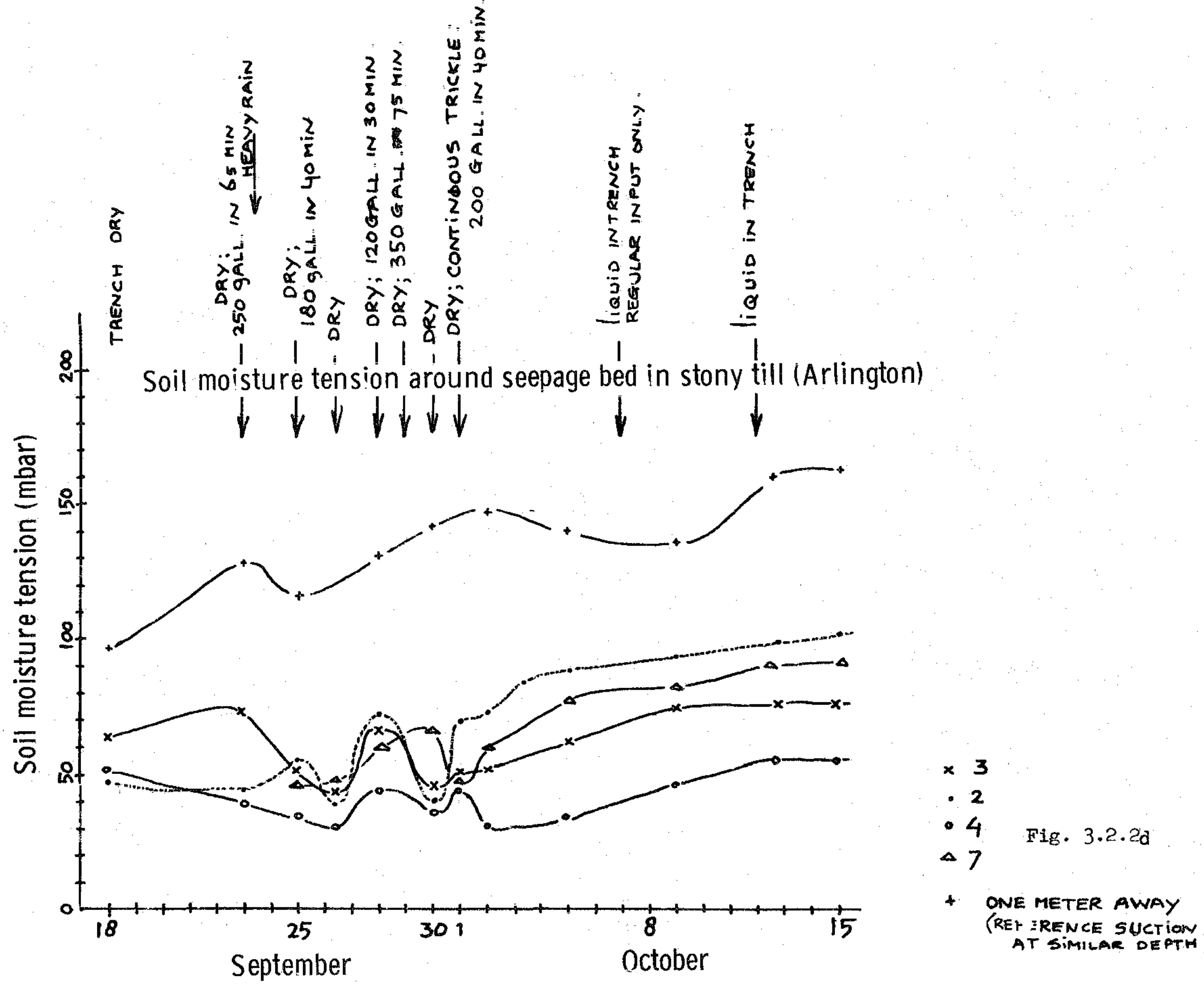

Soil moisture tension around seepage bed in stony till (Arlington)
TRENCH DRY
DRY; 250 GALL. IN 65 MIN
HEAVY RAIN
DRY; 180 GALL. IN 40 MIN
DRY
DRY; 120 GALL. IN 30 MIN
DRY; 350 GALL. 75 MIN.
DRY
DRY; CONTINUOUS TRICKLE: 200 GALL. IN 40 MIN.
liquid IN TRENCH REGULAR INPUT ONLY.
liquid IN TRENCH
Soil moisture tension (mbar)
0
50
100
150
200
18
25
30 1
8
15
September
October
× 3
• 2
o 4
△ 7
+ ONE METER AWAY (REFERENCE SUCTION AT SIMILAR DEPTH).

Fig. 3.2.2d

only 90 gallons/day. But effluent moves not only through the bottom of the bed, but also through the sidewalls due to gradients in the soil water potential alone, since strict horizontal movement is not effected by gravity. Assuming a potential gradient of unity horizontally (see values from tensiometers 5 and 6) we obtain flow values on July 21 of 19 gallons/day at 60 mb (K = 6 mm/day sidewall area: 0.2x 61.6 m^2 = 12.3 m^2). In August, the potential gradient was one-third lower and flow through sidewalls was estimated at 20 gallons/day at 40 mb. (K = 18 mm/day). For one trench, 10 gallons/day. Total flow can therefore be estimated at 69 gallons/day for July 21 and 135 gallons/day for August 14. On both dates effluent stood 20 cm deep in the trenches. The first value is within a reasonable 15% of the measured loading rate of the system (= 80 gallons/day, measured during one week in July by Mr. Ripp, resident of the home). These calculated amounts of flow are estimates based on separate one-dimensional vertical and horizontal flows. In the real two dimensional flow system flow lines will be curved. Real flow rates can be determined by modelling such a system using a computer (Chapter 4). However, we do not expect such calculated values to be much different from these estimates. The second series of experiments was started on September 18, when both trenches were empty of liquid (the occupants of the house had been on holidays for three weeks, Aug. 14-Sept. 4). Starting on September 23, additional water was added to the system, through a basement faucet, as during the first experiment. Large amounts of liquid were added in relatively short periods of time (see Fig. 3.2.2d). The effluent was absorbed by the soil within one or two days. Tensiometers reacted clearly to this intermittent dosing pattern (Fig. 3.2.2d). For example, after adding 180 gallons in a 40 minute period on September 25, soil tensions moved down around the trench. The trench was empty on September 27, and tensions moved up to relatively high values on September 28 as a result of drainage. Then another 120 gallons were added. The next day the trench was empty ("dry"). The high amount of 350 gallons was added, and tensions reacted strongly. Two days later, however, the trench was dry and tensions had increased again since the previous day. Starting on October 1 the method of adding water to the system was changed to a continuous trickle at the rate of 200 gallons per day. After that, the trench nearly filled with effluent and remained so to the end of the experiment (October 15). Addition of water was stopped on October 7, when the trench started to overflow. Since then only the regular daily input (80 gallons) entered the system. In the period October 2 to 15, tensions around the bed gradually increased to levels remarkably similar to those measured on July 21 at the start of the experiment. Such increasing tensions around a bed that contains ponded effluent indicate an increase in hydraulic resistance of the crust. This is probably caused by increasing anaerobic conditions that induce the formation of organic products that clog soils pores (see 3.2.5). The identical hydrological situation at the start and at the end of the series of experiments may indicate a dynamic equilibrium specific for this particular system. Air diffusing through the soil to the crusted sidewalls of the bed, will permit break-down of anaerobically produced organic substances there. This process is influenced by soil texture and position of trenches. Stronger diffusion, for example in a coarse porous material and with trenches placed closer to the surface, could result in an equilibrium at a lower suction, and thus a higher infiltration rate made possible by a diminished resistance of the crust. Inflow of effluent with a lower B.O.D. (after aeration), could have the same effect. More experiments in different soils are needed to investigate this aspect (see Section 4). In any case, soil moisture tensions measured in this study were never lower than 40 mb. The data show that only about one week of ponding is sufficient to create soil moisture tensions similar to those present after ten years of system use. This demonstrates the unfavorable effects of overloading.

Table 3.2.2.1. Bacteriological analyses, July, 1970 (high tension below seepage trench).

Location	Bacterial Counts /gram		
	EMB	PCA	m
10 cm below trench (tens. #3)	None (on 10^3 lowest)	6.7×10^5	0
25 cm below trench (tens. #2)	None (only 2.1×10^3 molds	3	0
40 cm below trench	Not determined	5×10^4	0
10 cm at side of trench (tens. #4)	1.2×10^3 (purple, no fecal recorded	10×10^6	0
15 m distance from the trench at 80 cm depth (control)	None (1×10^3 mold)	1.4×10^5	0
	Distribution Box 16×10^3 (4×10^3 fecal)	12.3×10^6	260

numbers of numbered tensiometer locations.

Table 3.2.2.2. Bacteriological analyses, September, 1970 (low tension below seepage trench).

Location	Bacterial Counts /gram	
	EMB	PCA
2m upslope from trench (control) 80 cm depth	$<10^2$ >10	4×10^4
(#3 = 10 cm below trench)	9×10^2	1.2×10^6
(#2 = 25 cm below trench)	$<10^2$ >10 (~40)	4×10^5
(#4 = 10 cm to side of trench)	9×10^2	1.8×10^6
(#7 = 30 cm to side of trench)	250	17×10^6

#numbered tensiometer locations.

M = m-ENTEROCOCCUS AGAR COUNT

Percolation test results showed an average infiltration rate of 3 min/inch (900 cm/day) (Fig. 3.5.2.13 and 3.5.2.23). Test results showed that actual flow rates were much lower. One must conclude that the infiltration rate established by the use of clear water and a fresh soil hole, does not yield a representative figure for the real flow rates of effluent into soil as they occur below a septic tank seepage bed. These low infiltration rates result from processes of unsaturated flow and have a very favorable effect on the reduction of amount of fecal microorganisms in the soil around the trench.

Two series of microbiological samples were taken. The first in July, when soil moisture tensions around the trench were as high as 80 mb. The results of the tests (Table 3.2.2.1) show that EMB counts in samples taken 10 cm below the trench, were as low as control samples taken 10 meters away. This means that bacteriological purification of effluent (from a count of 16×10^3 coliforms/ml (of which 4×10^3 is fecal) in the effluent to none in the soil, is accomplished after percolation through only 10 cm of soil. Samples in September (Table 3.2.2.2) were taken after aeration of the bed, resulting in a lower crust resistance and a soil tension of 30 mbar. At the faster rate of percolation, purification needed a larger volume of soil. At 10 cm below the trench an EMB count of 9×10^2/gram was made. At 25 cm below the trench the count was about 40/gram still higher than originally below the bed in July. At both dates counts from samples taken at the sides of the bed were higher than those taken below the bed. This could indicate a faster movement of effluent through the sidewall of the bed. Soil moisture tensions gave the same indication.

3.2.4. Conclusions

Results of the research on the seepage field at the Poultry Farm can be summarized as follows.

1. In July, 1970 the system was operating satisfactory only because of a low loading rate. Although the effluent stood 20 cm deep in the bed, soil moisture tensions around the bed were around 80 mbar and infiltration into the soil was very low. This indicated the presence of a boundary layer, called a "crust", of considerable hydraulic resistance.

2. After the system was pumped "dry" and aerated for about a week, effluent was absorbed by the soil at a faster rate than before. Suctions were then at 40-50 mb in the surrounding soil. Apparently, aeration had permitted partial break-down of the crust, reducing its hydraulic resistance.

3. One week of ponding after the period of aeration was sufficient to restore tensions around the bed similar to those measured at the beginning of the experiment.

4. Processes of unsaturated flow were very effective in allowing disappearance of fecal microorganisms within very short distances from the trench.

5. Use of the results of the crust test and measurements of hydraulic gradients in the soil made it possible to estimate infiltration rates from the trench much more realistically than would have been possible from the results of the State Percolation Test. Results show that there is no fixed relevant percolation rate that applies to the system. Rather, there is a range of possible rates as a function of system management.

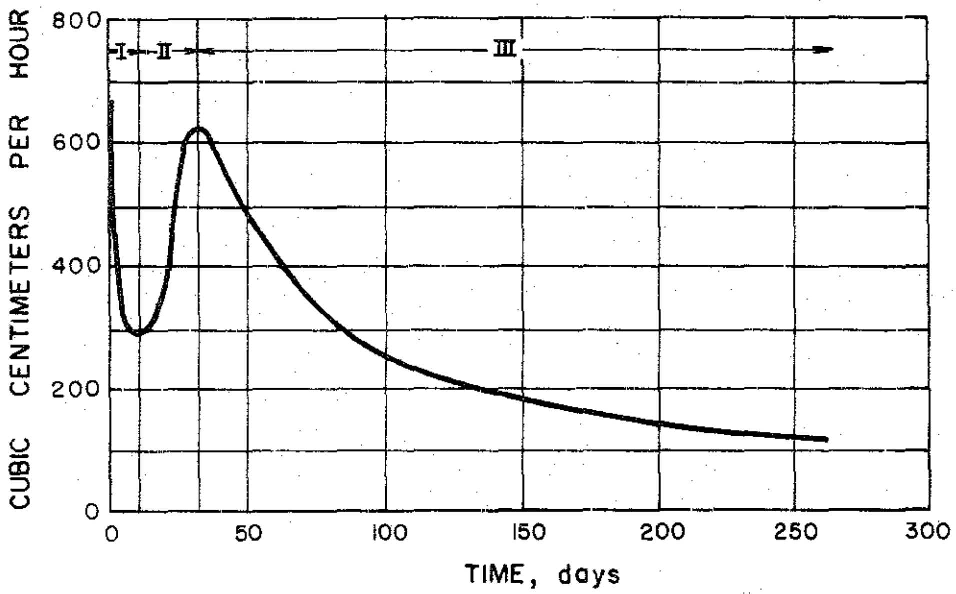
3.2.5. The process of soil clogging

3.2.5.1. Introduction

The study of the soil disposal system at the Poultry Farm clearly demonstrates that the short term infiltration rate of clean water is not a good measure of the long term capacity of a soil to accept effluent. A distinction has to be made between infiltration at the interface between soil and liquid and the potential percolation rate of water once it has entered the porous structure of the soil (McGauhey and Krone, 1967). Hillel and Gardner (1969, 1970a, 1970b) studied the effect of impeding layers on infiltration, in quantitative terms, relating the infiltration rate into crusted soil to basic hydraulic properties of the crust and the underlying soil. The effect of an impeding layer present over the top of a soil column during infiltration is to decrease the potential head at the soil surface, thus reducing the driving force, and to decrease the soil water content (and correspondingly the hydraulic conductivity) of the infiltrating column. The crust test procedure (Section 2.3) is based on these principles. Processes of soil clogging at the interface of soil and seepage bed create such an impeding layer under the influence of several factors (McGauhey and Krone, 1967, p. 39-70):

1. The physical factor. The following subfactors contribute to clogging: compaction of soil by machinery at the site of construction of a seepage bed; smearing of soil surfaces by the excavation equipment; concentration of fine particles in the upper few centimeters of soil by vibration during construction; concentration of fine particles by raindrop impact.

2. The chemical factor. Ion exchange, after introduction of sodium through water softening, may lead to deflocculation of clayey soil at low salt concentrations at the soil-seepage trench interface.



TYPICAL PERCOLATION RATE CURVE FOR PROLONGED WATER SPREADING ON A SOIL CORE OCCURRING IN THREE PHASES (From McGauhey and Krone, 1967).

Fig. 3.2.5.2

3. The biological and organic factors. A black, slimey concentrate of organic matter and associated mineral colloids and growths of microorganisms on the surfaces of walls of seepage trenches constitutes the most restrictive clogging layer of the system.

3.2.5.2. Biologic clogging of infiltrative soil surfaces

A typical percolation rate curve for prolonged water spreading on a soil core is shown in Fig. 3.2.5.2 (from McGauhey and Krone, 1967). The first decrease in infiltration (Phase I) may be caused by slaking of the soil surface, the subsequent increase (Phase II) may result from the removal of entrapped air by solution in the percolating water (Christiansen, 1944) and the long-term decrease (Phase III) in permeability results from microbial activity as has been demonstrated by Allison (1947). By applying sterile water to sterile soils, he showed that Phase III does not occur in the absence of organisms and that the high rate achieved in Phase II is maintained indefinitely. The microbial action involved in the decline in permeability (Phase III) is primarily that of anaerobic organisms in accumulating organic matterial in the soil pores (McGauhey and Winneberger, 1964). In well drained soils aerobic organisms are active in breaking down such compounds. This process is stopped by saturation, even with bacteria-free water, and consequent blockage of gaseous diffusion of oxygen (Thomas, _et al_., 1968) into and within the soil system. Dissolved oxygen carried down by water is inadequate in amount to maintain the aerobic environment necessary for decomposition of organic matter. The existence of reducing conditions at the wall of the trench is indicated by the dark gray to gray zone, as much as a few cm thick, in sandy soil adjacent to the black shiny coating.

Thomas, et al. (1966) studied biological clogging of sand in lysimeters, that were dosed at a rate of 5 gallons/day/sq. ft. A sharp decline in infiltration rate coincided with the onset of anaerobic conditions as indicated by cessation of nitrification. Sulfide accumulation resulted from the anaerobic environment and was not considered to be a primary cause of clogging. The clogging mechanism under anaerobic conditions was correlated with build-up of high contents of polysaccharides, polyuronides and organic matter in the first cm of the soil, that accounted for 85% of the total impedance over a thickness of 0-6 cm of soil. The recovery of the infiltration rate after aeration resulted from destruction of the clogging compounds that had accumulated under anaerobic conditions. Mitchel and Nevo (1965, as cited by McGauhey and Krone, 1967) also showed a positive correlation between accumulation of polysaccharides in the soil profile and reduction of its infiltrative capacity. These workers suggested the operation of a dynamic equilibrium at any level of aeration between polysaccharid-producing organisms (anaerobic), and polysaccharide-destroying organisms (aerobic).

Harris et al. (1966) demonstrated an increase of soil aggregate stability in surface soil after addition of sucrose, as a result of microbial production of organic compounds, both under aerobic and anaerobic conditions. Rates of decomposition under aerobic conditions of compounds that were produced anaerobically proceeded rapidly at temperatures over 15°C, and much slower at lower temperatures. Decomposition and synthesis of the organic compounds is accomplished not by a single type of bacteria but rather by a population of types as determined by environmental conditions. Since similar processes of formation of organic compounds under anaerobic conditions can be expected to obtain in biogenic crusts below seepage beds, results reported by Harris et al. (1966) should also apply to the soil clogging problem. This means that research efforts should focus on environmental properties in the soil and related microbiological activity as they affect the hydraulic resistance of crusts at any specific time.

3.2.5.3. Conclusion

Development of anaerobic conditions in soil, immediately below and around a seepage bed, leads to the production of organic compounds that clog the soil pores at the interface. Clogging increases the hydraulic resistance of the soil, thus reducing the infiltration rate into the adjacent unclogged soil, that as a result may become unsaturated even when the seepage bed is filled with effluent. Some clogging may be beneficial in sandy soils because it slows the flow of effluent into the soil, and helps maintain the unsaturated and aerated condition that is favorable to decomposition of organic waste. Too much clogging, however, may increase the hydraulic resistance so much that the infiltration rate is reduced to negligibly low values (see Section 3.2). Dosing (intermittent application) of effluent may be necessary to allow for periods of aeration during which organic materials in the crust can be broken down, thus restoring the infiltrative capacity (Section 3.2). Systems placed superficially in soils with high permeability may work quite well without a dosing regime (see Section 3.4.2). In either case, however, a better understanding of the relevant processes is needed in quantitative terms to estimate the hydraulic resistance of a "crust" as a function of the dosing regime, effluent quality and soil properties.

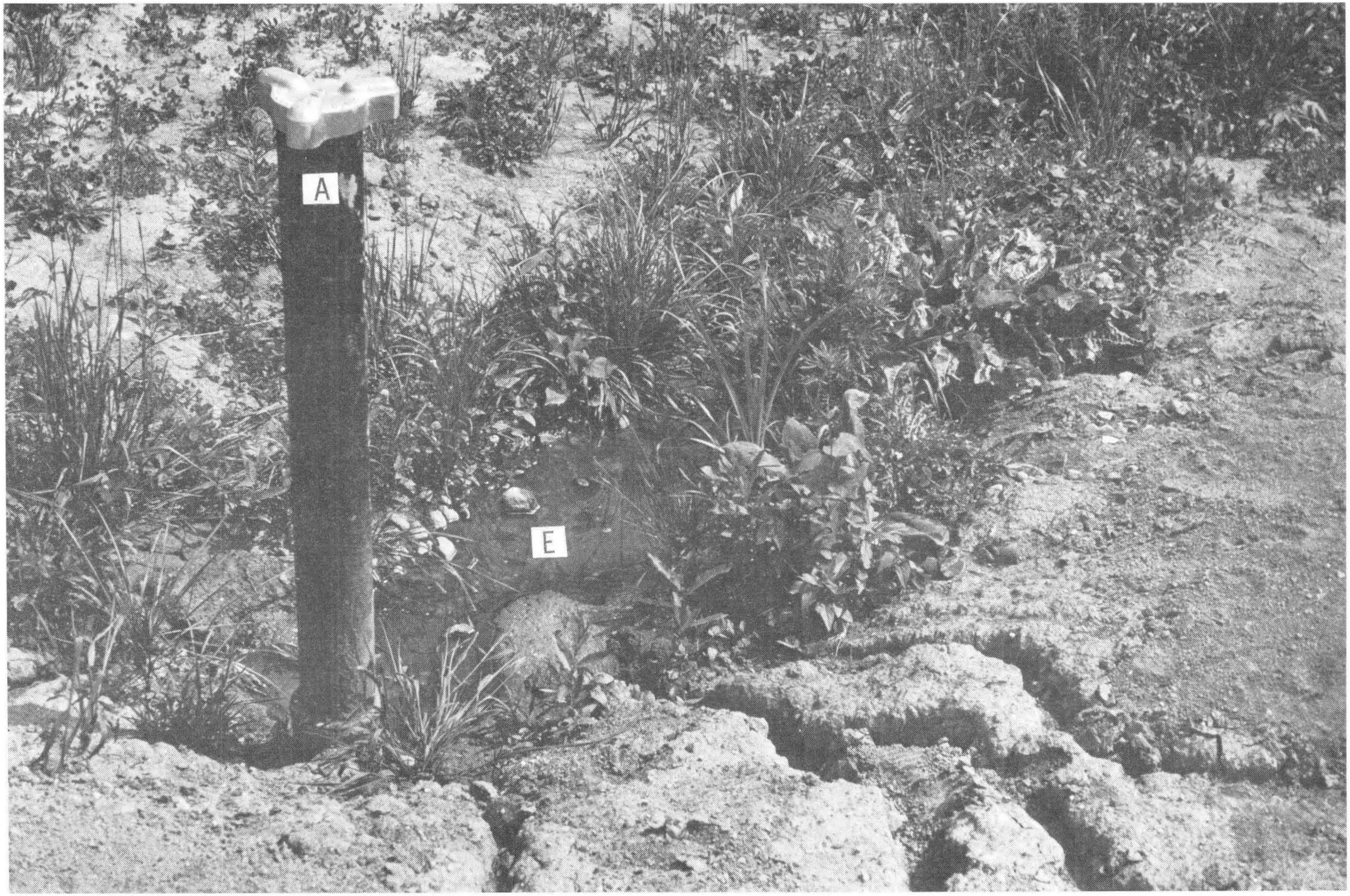
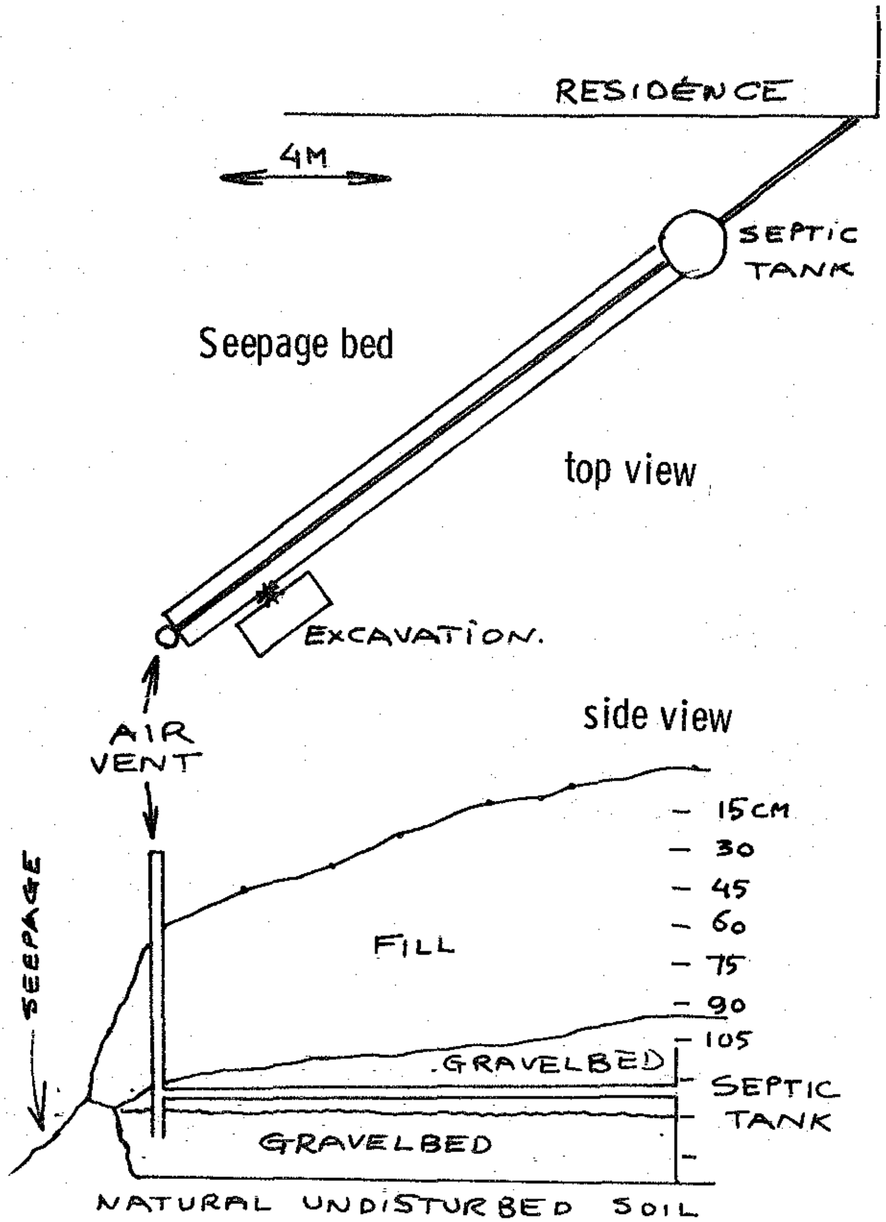
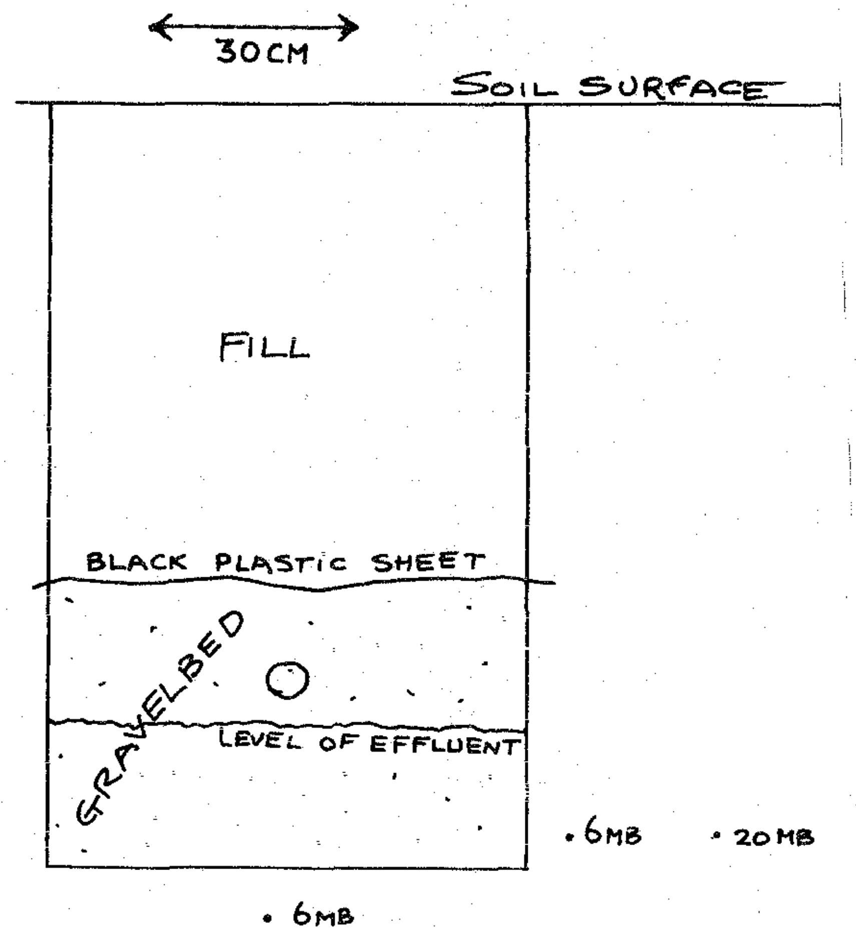


Photo 3.3 Air vent (A) at the lower part of the soil absorption system in Ontonagon clay. Raw effluent (E) is flowing from the system because low conductivity of the soil does not permit it to absorb the liquid.

SOIL ABSORPTION SYSTEM, Ontonagon silty clay loam (Ashland)





Cross section of seepage bed
with locations of tensiometers

Fig. 3.3.1.

3.3. Soil absorption system in Ontonagan silty clay loam near Ashland, Wisconsin

3.3.1. Introduction

The purpose of this investigation was to assemble quantitative data from a soil absorption system that did not function properly, because of the restricted permeability of the soil. This system was constructed in the spring of 1970 and was investigated in the following August. The local conditions are representative of 2,500,000 acres of red clayey soils in northern and eastern Wisconsin. A cross section of the system is shown in Fig. 3.3.1. The upper surface of the gravel bed was at a depth of 36" (90 cm) in the B3 horizon and was covered with a black sheet of plastic to intercept moisture moving down from the topsoil through the fill of the trench. The envestigators made a deep excavation next to the seepage bed (see Fig. 3.3.1) to expose a representative portion of the soil surrounding the system. Effluent was found to be ponded in the 45 cm thick gravel bed to a level of 10 inches (25 cm) above the bottom. The loading rate of the system was estimated to be 180 gallons/day. Soil moisture tensions were measured around the gravel bed and saturated hydraulic conductivity was determined with the Bouwer double tube method in the main horizons of an adjacent undisturbed profile that was also described (see section 6.1) and physically analyzed (Fig. 3.3.1a and 3.3.1b). Three state percolation tests and a crust test were made at the level of the seepage bed in the B3 horizon. Soil absorption was insufficient to dispose of all effluent introduced into the system as was evidenced by considerable seepage of raw septic tank effluent to the surface and downslope from the lower end of the seepage bed, near the air vent (see photo 3.3). No bacteriological analyses were made due to transportation problems.

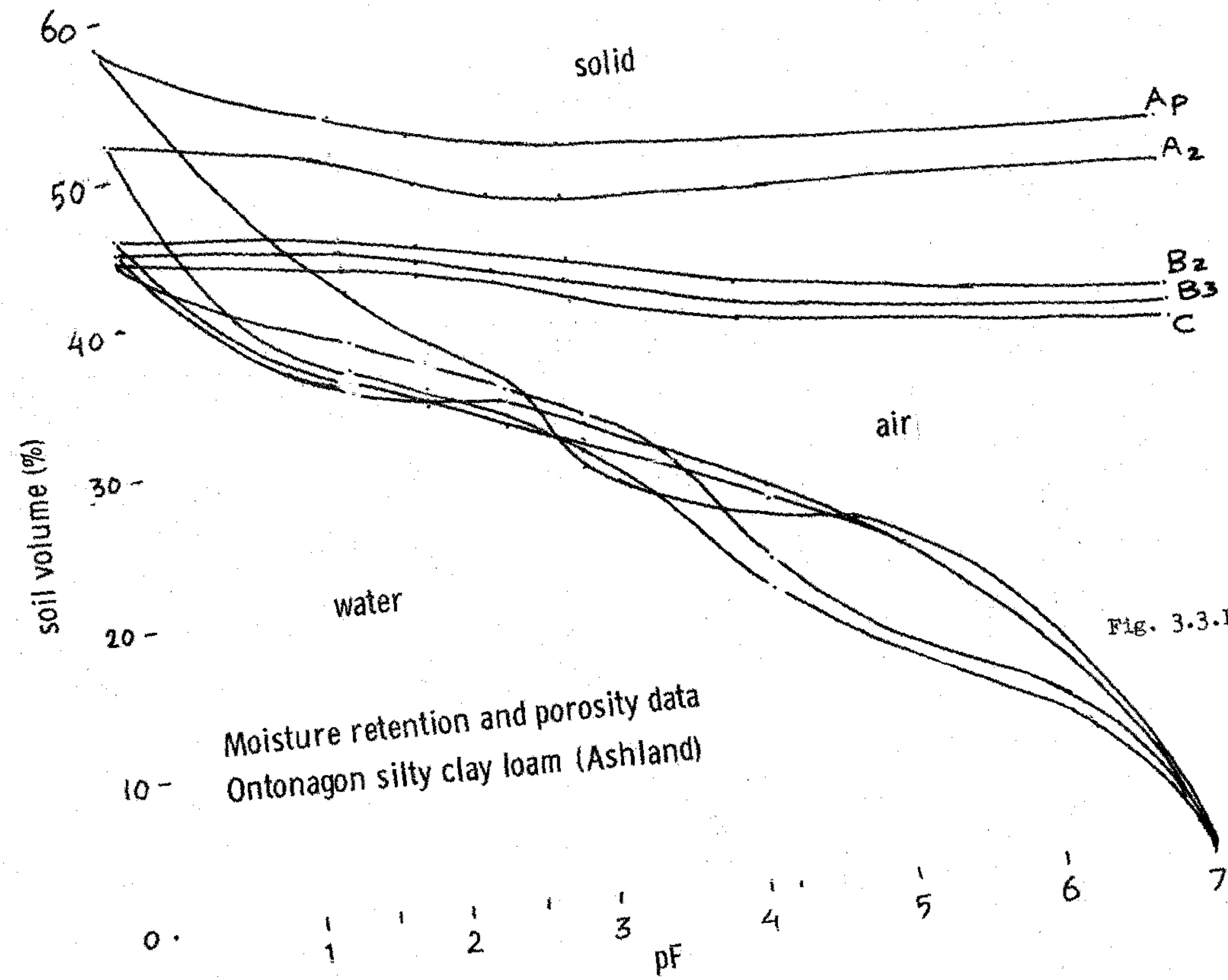

solid
air
water
Ap
A2
B2
B3
C
soil volume (%)
60
50
40
30
20
10
0
1
2
3
4
5
6
7
pF
Moisture retention and porosity data
Ontonagon silty clay loam (Ashland)

Fig. 3.3.1a

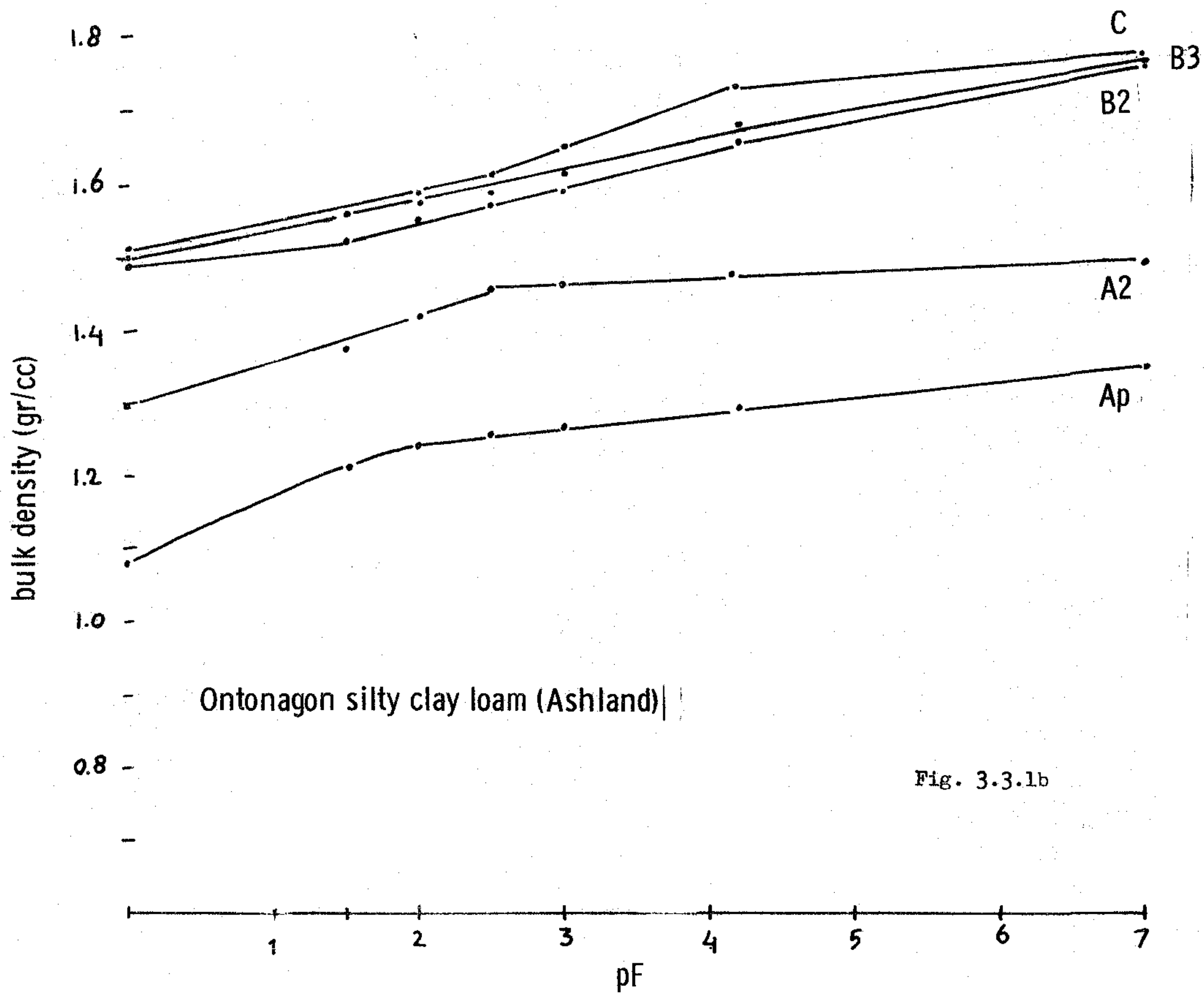
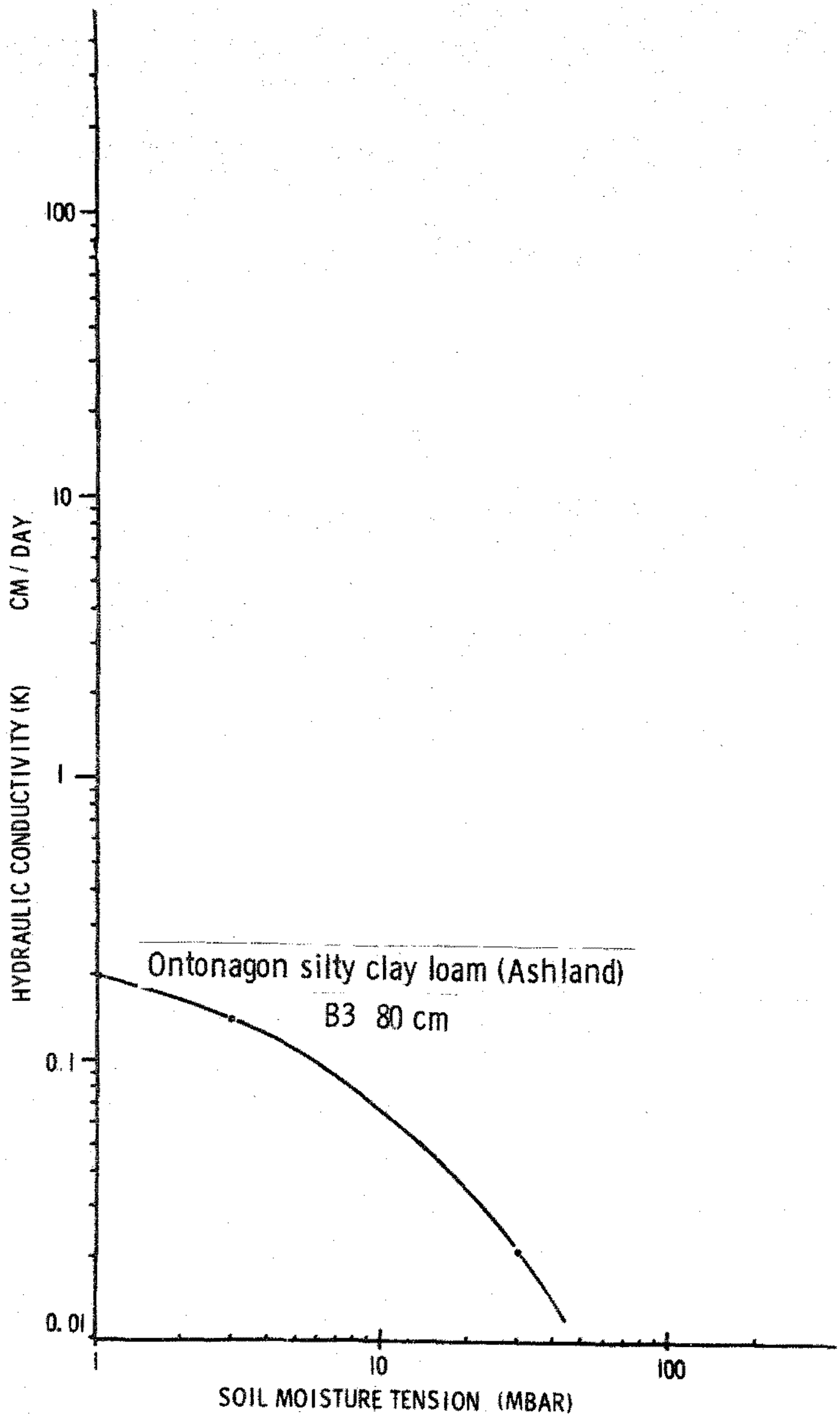

1.8
1.6
1.4
1.2
1.0
0.8
bulk density (gr/cc)
C
B3
B2
A2
Ap
Ontonagon silty clay loam (Ashland)
1
2
3
4
5
6
7
pF

Fig. 3.3.1b



HYDRAULIC CONDUCTIVITY (K) CM / DAY
100
10
1
0.1
0.01
Ontonagon silty clay loam (Ashland)
B3 80 cm
1
10
100
SOIL MOISTURE TENSION (MBAR)

Fig. 3.3.2

3.3.2. Results and Discussion

Results of the State Percolation Test and the Bouwer-K measurements are reported in Table 3.3.2. Fig. 3.3.2 gives the result of the crust test measurement.

Table 3.3.2. Hydraulic test results of an Ontonagon silty clay loam near Ashland, Wisconsin.

Soil horizon	K_{sat} (Bouwer test) (cm/day)	Perc. test (State Perc. Test: min/inch)
A2	20	no test
B2	4	no test
B3	--	1400

The result of the State Percolation Test shows that the percolation rate is much slower than the critical value of 60 min/inch. According to the State law, therefore, the site is not suitable for a soil disposal system. The exact measurements of hydraulic conductivity and moisture tensions around the seepage bed confirm this conclusion. Soil moisture tensions around the bed (6 mb) were near saturation. The bottom area of the trench is $15 \times 0.75 = 11.25\ m^2$, the sidewall area in contact with effluent is $2 \times 15 \times 0.2\ m^2 + 2 \times 0.75 \times 0.20\ m^2 = 6.3\ m^2$. The hydraulic conductivity at 6 mb suction at the depth of the seepage bed is 1 mm/day (Fig. 3.3.2). Assuming a hydraulic gradient of unity, both vertically (because of gravity) and horizontally (because of capillary forces), total flow can be estimated as 17 liters (4 gallons) a day. This is such a low amount that for all practical purposes, the soil can be considered impermeable. Thus, the most basic condition for a soil absorption system is not met. Alternatives at this site would be to construct the seepage bed closer to the surface, where conductivity and porosity (Fig. 3.3.1a and b) are higher, or perhaps, to build a mound system (see Section 3.6). This site seems suitable for a mound system, because of the relatively high conductivity, high porosity and low bulk density of the upper soil horizons to a depth of 60 cm. Moreover, the site is located on a gentle slope that would make lateral seepage of effluent through the topsoil quite likely. However, more study of experimental mound systems will be necessary before sure advice can be given as to design of such a system.

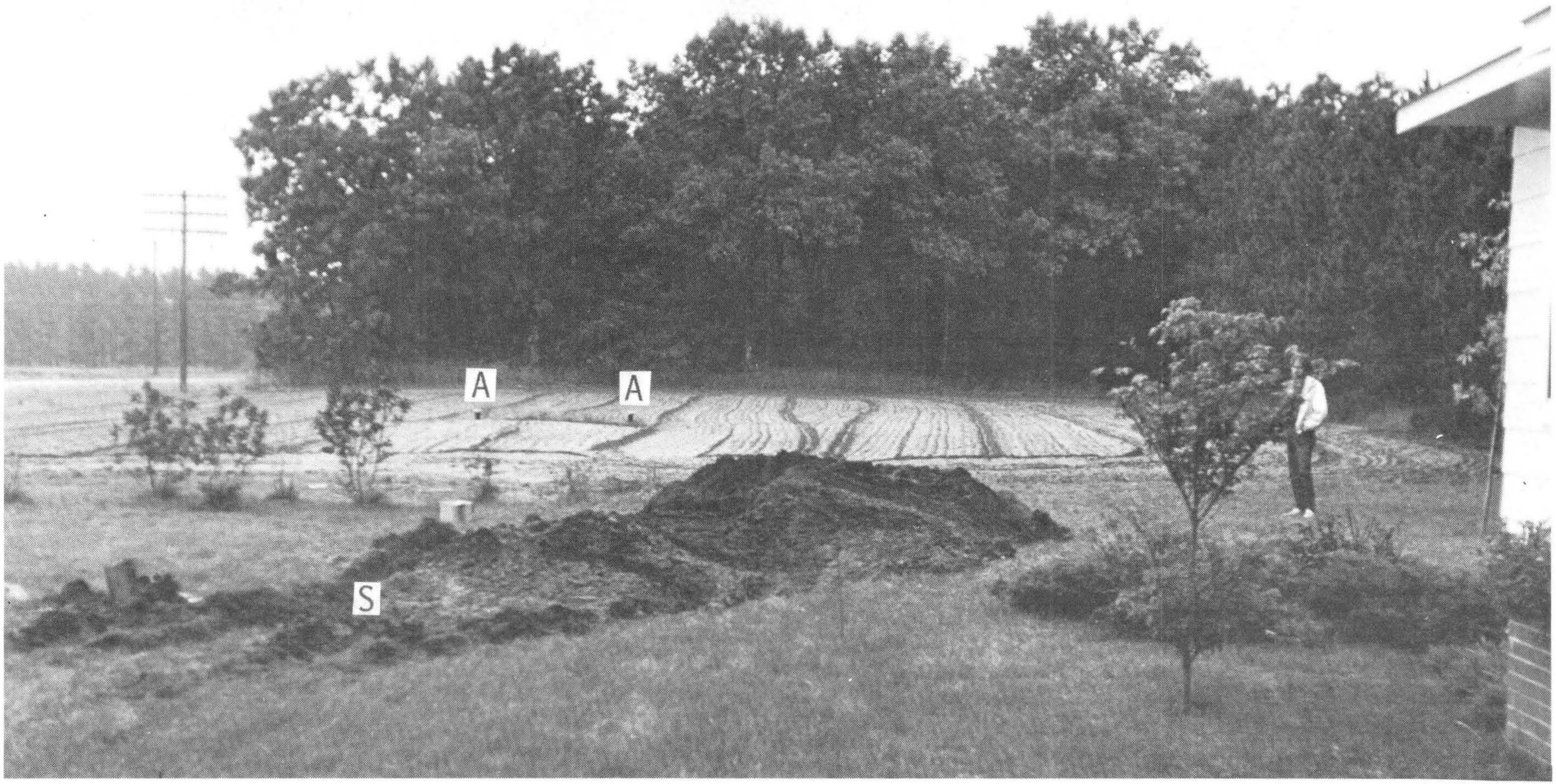
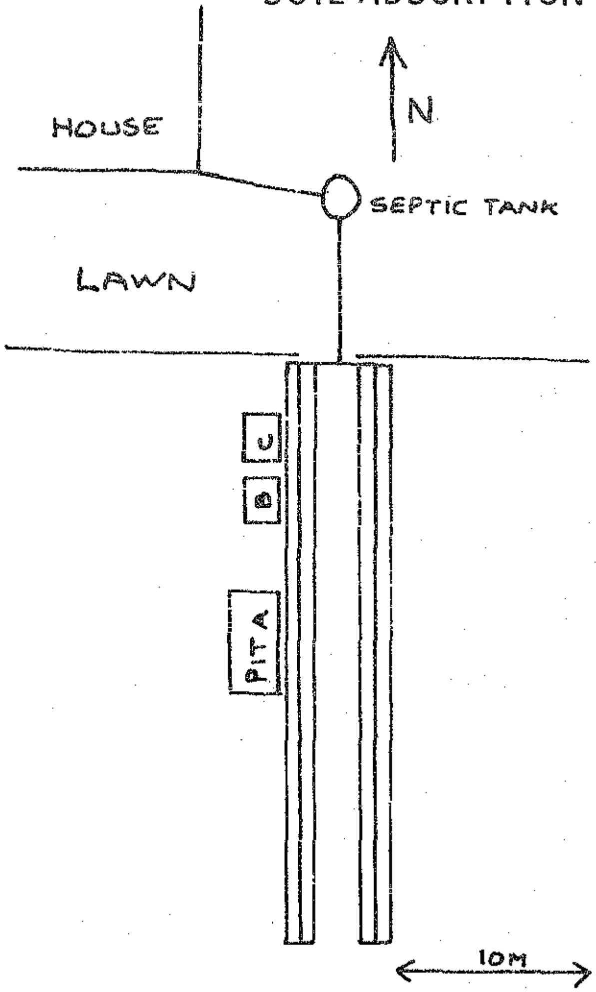
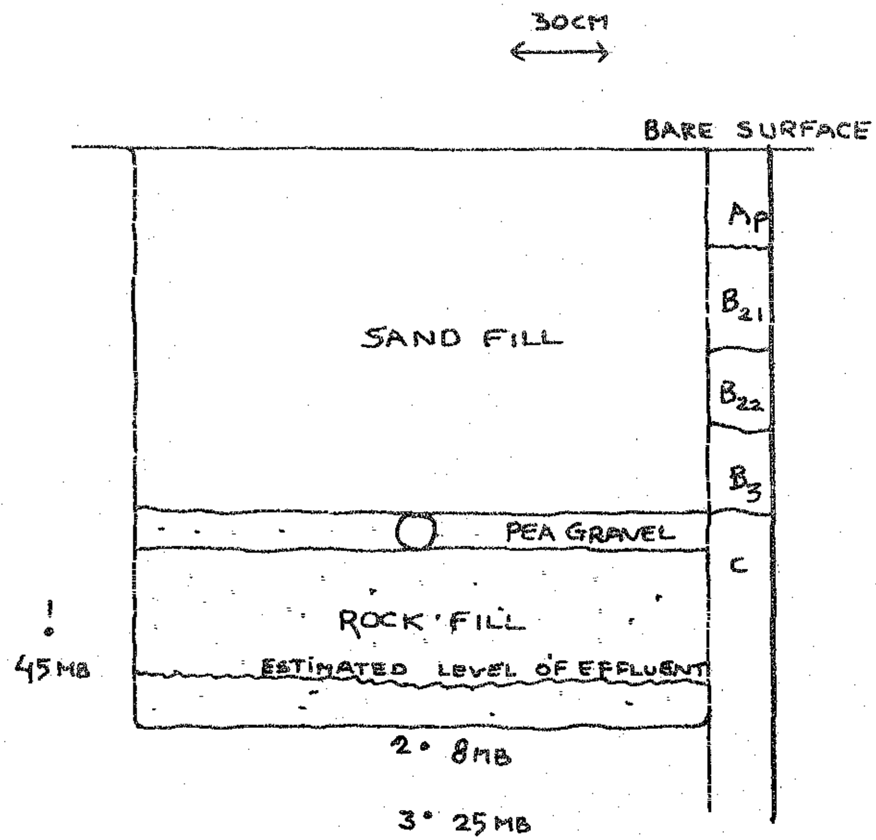


Photo 3.4.1 Absorption field in Plainfield loamy sand at Hancock.
The septic tank (S) is near the house, the two airvents (A) mark the end of the seepage bed (see diagram of the system, Figure 3.4.1).

SOIL ABSORPTION SYSTEM IN PLAINFIELD LOAMY SAND (Hancock, Wis)



Top view of seepage bed



Cross section of trench with location of tensiometers at location B.

Fig. 3.4.1.

3.4. Soil absorption systems in Plainfield loamy sand

Two systems of different age were studied in the same type of soil, to obtain data on effects of aging of septic tank drainage beds. Generally, systems are expected to work for a period of 15 to 20 years (Coulter et al., 1960).

3.4.1. The system at the U.W. Hancock Agricultural Experiment Station

3.4.1.1. Introduction

This very large system was built in 1969, and had functioned quite well. We investigated this system in July, 1970 (Photo 3.4.1). A large pit (Pit A) was dug next to the seepage bed, the bottom of which was at 6 ft. below the soil surface (Fig. 3.4.1) to enable flow of liquid from the septic tank into the bed by gravity only. This great depth offered many technical problems, as the sand walls of the pit caved in several times, even when braced. The soil around the seepage bed had a relatively dry appearance at Pit A. After excavation it was found that the gravel in the bed was still clean and that effluent had not yet reached this far along the trench. We may conclude that more than half of the length of this bed, and presumably of the other one (not investigated) had not been used for effluent disposal during the first year of operation of the system. Two additional pits (B and C, Fig. 3.4.1) were dug closer to the septic tank. The trench contained effluent at both locations. Tensions measured around the trench at Pit B are plotted in Fig. 3.4.1. Samples for microbiological analysis were taken at Pits C and B and at three depths in the septic tank. A crust test was made at the 90 cm depth in Pit A, in which the soil profile was described also. Two Bouwer tests were made at the 120 cm depth in the undisturbed soil surrounding the seepage bed. Undisturbed large core samples were taken from the soil at the same depth as the gravelbed, for determination of moisture retention characteristics, porosity and bulk density.

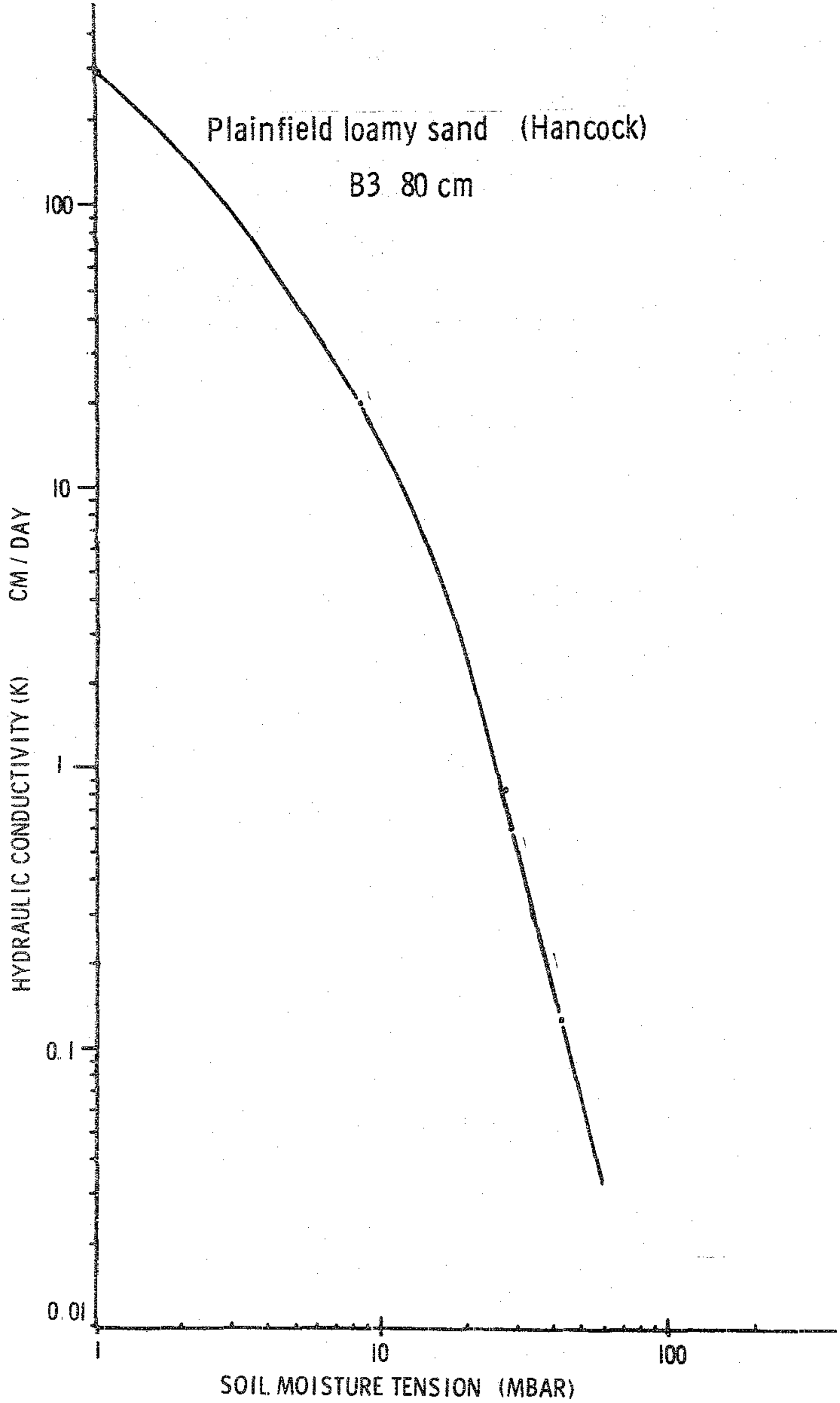

Plainfield loamy sand (Hancock)
B3 80 cm
100
10
1
0.1
0.01
HYDRAULIC CONDUCTIVITY (K) CM / DAY
1
10
100
SOIL MOISTURE TENSION (MBAR)

Fig. 3.4.1a

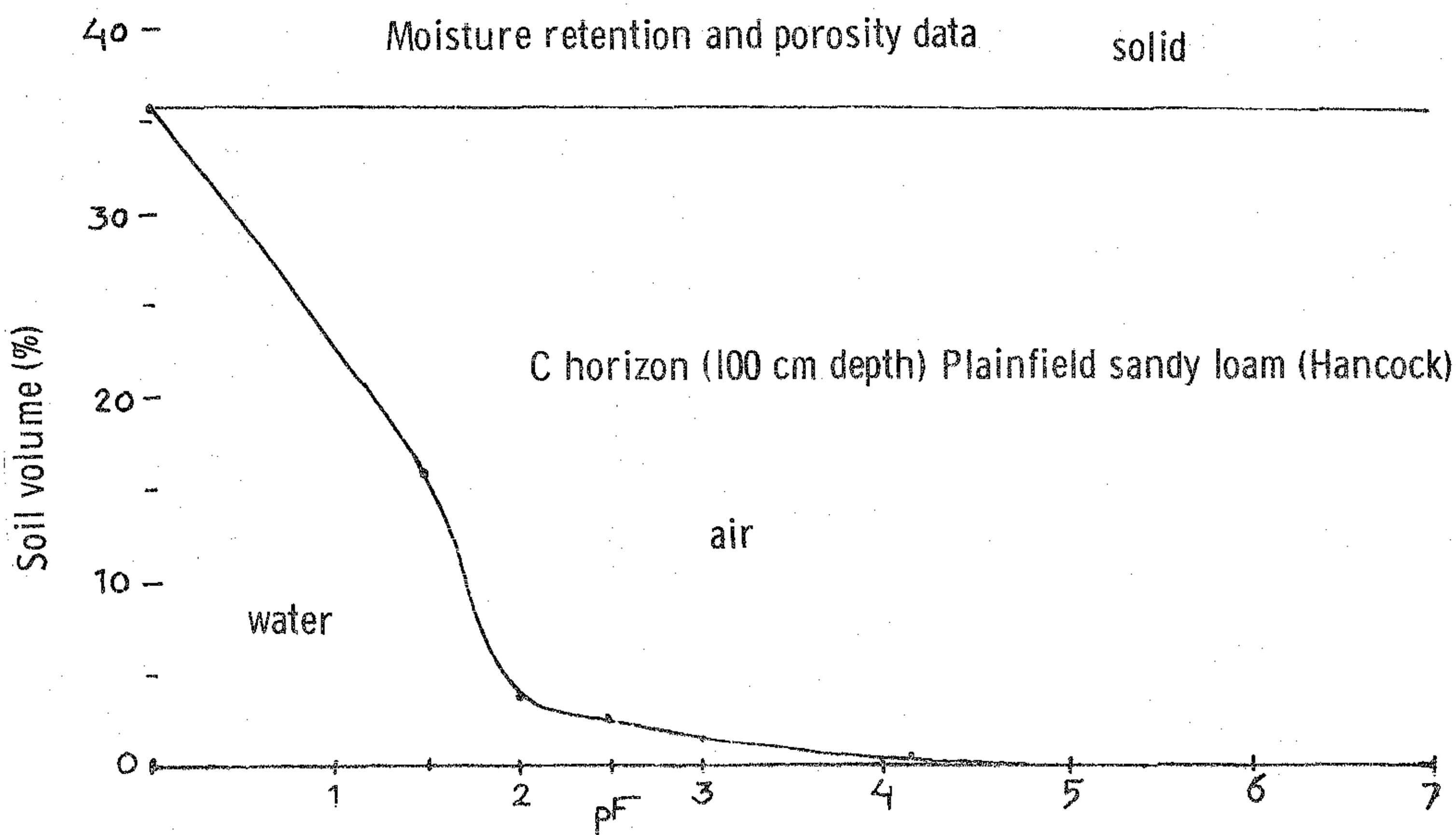

Moisture retention and porosity data
solid
C horizon (100 cm depth) Plainfield sandy loam (Hancock)
air
water
Soil volume (%)
40
30
20
10
0
1
2
3
4
5
6
7
pF

Fig. 3.4.1b

3.4.1.2. Results

Results of the State Percolation and Bouwer Test are presented in Table 3.4.1.1. Crust test data yielded the curve of Fig. 3.4.1a.

Table 3.4.1.1. Hydraulic conductivity (K) and Wisconsin State Percolation Test measurements.

Horizon	Bouwer-K (cm/day)	State Perc. Test (min/inch)
C (90 cm)	300	2(≈1600 cm/day)

Fig. 3.4.1b presents data on physical characteristics of the C horizon that surrounds the seepage bed. Results of microbiological analyses are in Table 3.4.1.2. The seepage bed was 6 feet below the surface, and this created considerable difficulties with sampling, as the deep holes caved in several times. The number of observations with tensiometers is therefore rather limited. At 5 cm below the trench the low soil moisture tension of 8 mb was measured indicating the presence of a weak crust. At the 35 cm depth, tension was 25 mb. Crust test data (Fig. 3.4.1a) show that at 8 mb, K is about 30 cm/day. The hydraulic gradient below the trench is about $1\frac{1}{2}$, so the amount of flow is estimated at a rate of about 45 cm/day. This is a relatively high rate which does not permit purification of the liquid in the distance observed. This system was the only one, of all systems investigated this season, in which such a high content of microorganisms existed at a distance of 30 cm from the bed. Unfortunately, no samples could be taken below the level of tensiometer 3.

3.4.1.3. Discussion of microbiological data by W. A. Ziebell

We observe from this study that the population of coliform organisms remains at a fairly constant level in the liquid in the septic tank, in the trenches and in the soil immediately below the trenches. Data from the

Table 3.4.1.2. Bacteriological analyses of septic tank effluent and soil around the seepage bed.

EMB count per gram	PCA	m	% Soil Moisture	Notes
(10^2 molds)	8×10^4	0	4.6	Control, 140 cm depth, 1 m from system (near Pit C).
11×10^4 (fecal on 10^3 plate)	92×10^6	1240	----	Effluent from line (obtained from a leak through the side of the trench.
(6×10^2 molds)	31×10^4 (many appear as actines)	0	9.7	Above bed. Note: plastic liner over the trench.
(11×10^2)	2×10^6 (actines)	0	3.8	10 cm above bed (Pit C).
(2×10^3 molds)	6×10^5	0	4.2	At sidewall of bed.
(3×10^2 molds)	12×10^5	0	4.3	10 cm at the side of the bed.
13×10^4 (fecal types on 10^2 plate)	184×10^6	180	7.9	Immediately below bed (Pit C).
4×10^4 (pink)	55×10^6	30	9.5	10 cm below bed (Pit C).
$>>10^4$	236×10^6	0	6.7	5 cm below bed (Pit B).
17×10^4	24×10^6	0	3.3	30 cm below bed (Pit B).
count per ml Samples from the septic tank (sampled 9/30/70)				
H_{30} 57×10^3 (18 fecal)	75×10^6	420	---	30 cm into tank.
H_{60} 48×10^3 (13 fecal)	90×10^6	390	---	60 cm depth.
H_{90} 46×10^3 (15 fecal)	24×10^6	100	---	90 cm depth.

m = m-ENTEROCOCCUS Agar count

Hancock site gave an average of 5×10^4 coliform organisms per ml of liquid or per gram of dry soil. Control samples taken at a distance of approximately 1.5 meters from the trench and at a depth of 1.25 meters revealed no coliforms (but a very large number of molds) on 10^{-2} dilution plates. Production of antibiotic substances by molds, actinomycetes and some bacterial species of the soil microflora may be significant in reducing coliform numbers.

Total bacterial counts on PCA agar gave about 66×10^6 organisms per ml in septic tank effluent, 92×10^6 organisms per ml in the trench tile liquid and 8×10^4 organisms per gram of dry soil in the control sample. Samples taken immediately below the trench gravel layer(within 2 cm) gave total counts of 184×10^6 to 236×10^6 organisms per gram of dry soil. These relatively high counts imply an increase in bacterial population either by multiplication or by accumulation through adsorption. The count dropped to 55×10^6 organisms per gram of dry soil at 10 cm and 24×10^6 organism per gram at 30 cm below the trench gravel in this sandy soil. The fact that the coliform total count remains at about 10^5-10^6/gram in this part of the soil profile suggests that this high population is not due to true coliform organisms but rather to some others, either of soil origin or originating from the septic tank.

Counts (as read by sheen formation on EMB plates) of fecal coliforn bacteria in samples of the septic tank effluent were in the range of 12×10^3 to 18×10^3 organism per ml. In effluent from the trench total coliform counts of 11×10^4 per ml were recorded with evidence of green sheen colonies on only 10^{-3} dilution plates* (i.e. counts in range of only 10^3per ml). In the drainage field no fecal coliform organisms were observed in soil at depths of 10 cm or more below the trench. Non-fecal and intermediate coliforms were found on the platings from soil to a depth of 30 cm below the trench at the Hancock site. This seems to indicate that fecal bacterial indicators are not

*Dilutions of 10^{-3} were the lowest used because at greater dilutions it was found that soil interfered with the color reaction on Levine's EMB agar.

Table 3.4.1.3. Survival of E. Coli in variously treated septic tank effluent.

	A		B		C	
Date	PCA(x10^6/ml)	EMB(x10^6/ml)	PCA(x10^6/ml)	EMB(s10^6/ml)	PCA(x10^6/ml)	EMB(x10^6/ml)
8/12	120	2	22	3.1	1-10	3
8/13	130	50	110	530	120	12
8/15	200	1-10	120	>10	35	$<10^5$
8/17	430	20	>>10	90	39	---
8/19	110	0.9	170	100	22	$<10^4$
8/21	>>1	8	>>1	161	$>10^5$	80×10^3 None Fecal org.
8/25	38	$<10^5$	107	5	$>10^4$	10-10

A = sewage, sterilized by millipore filter (0.47 micron filter)

B = heat-sterilized sewage

C = non-sterilized sewage

The sewage was obtained from a septic tank distribution box.

Each was inoculated with a 1% inoculum of a suspension of Escherichia cole ATCC 4348 grown in a broth of 5 grams peptone and 2 grams glucose/l to approximately 10^9 organisms/ml.

moving far into the soil of the absorption field but that other bacteria possibly ~~e.g.~~ Proteus and Pseudononas sp. (which can grow on the EMB plates) are present. Whether these are true "coliforms" from the sewage or are "coliforms" from the soil remains to be explained. The literature does show that A. aerogenes type coliforms are present in nature and it is possible that even those in the sewage can survive and grow. Relatively high infiltration rates of effluent (Section 3.4.1.2) may be a factor in increased penetration of coliform bacteria in this sandy soil assuming that these organisms are originating from the effluent.

Another point of interest is that samples taken adjacent to the sides of the trench and above it produced predominant mold growth on Levine's EMB agar and PCA agar, but no coliforms were recorded within the dilutions (10^{-2} or 10^{-3}) plated.

A decrease in the number of microorganisms may also be caused by natural die-off in effluent, while standing in the trench. A separate experiment was therefore conducted to investigate this aspect.

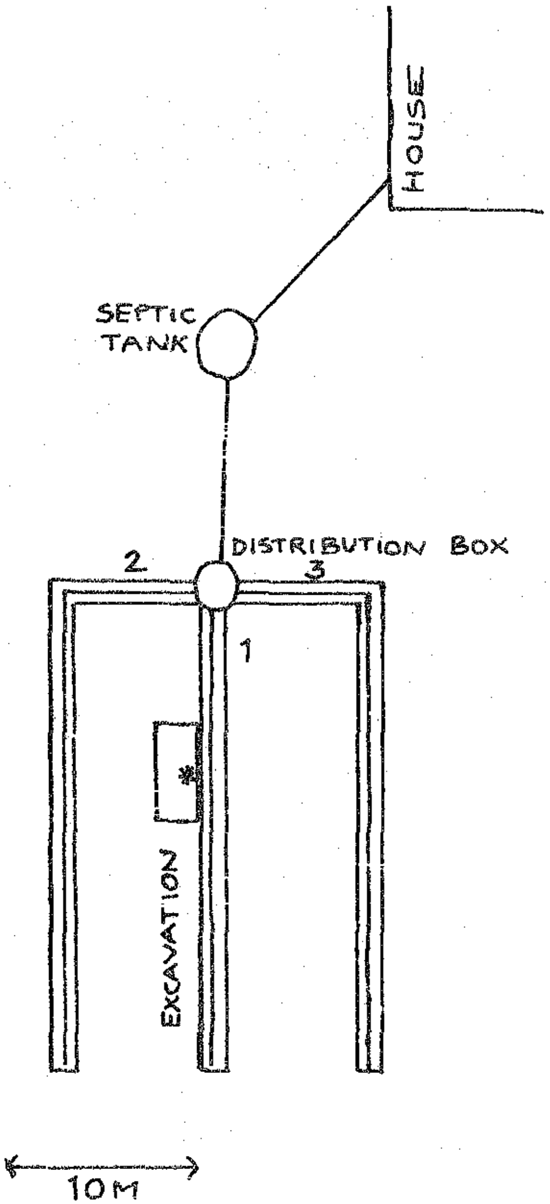
Die-off within 3 to 7 days of a known fecal coliform strain was observed after its inoculation into non-sterilized septic tank effluent (Table 3.4.1.3). Iwani (1966) reported a die-off of a known E. coli and a Streptococcus faecium strain in aerated manure water from approximately 2 (10^6) E.c./ml to 5 (10^4) E.c./ml and 1 x 10^6 S.f./ml to 4 x 10^4 S.f./ml in 5 days. Field evidence in support of this was obtained in the study of mound System I (Sec. 3.6.2) where effluent in the mound, well above the groundwater table, had no observable fecal coliform content. This effluent had not yet percolated through soil.

At Hancock, Streptococcus counts taken on m-Enterococcus agar gave 100-500 organism/ml for effluent from the trench tile line. Seldom were any detectable in the field below the trench, however.

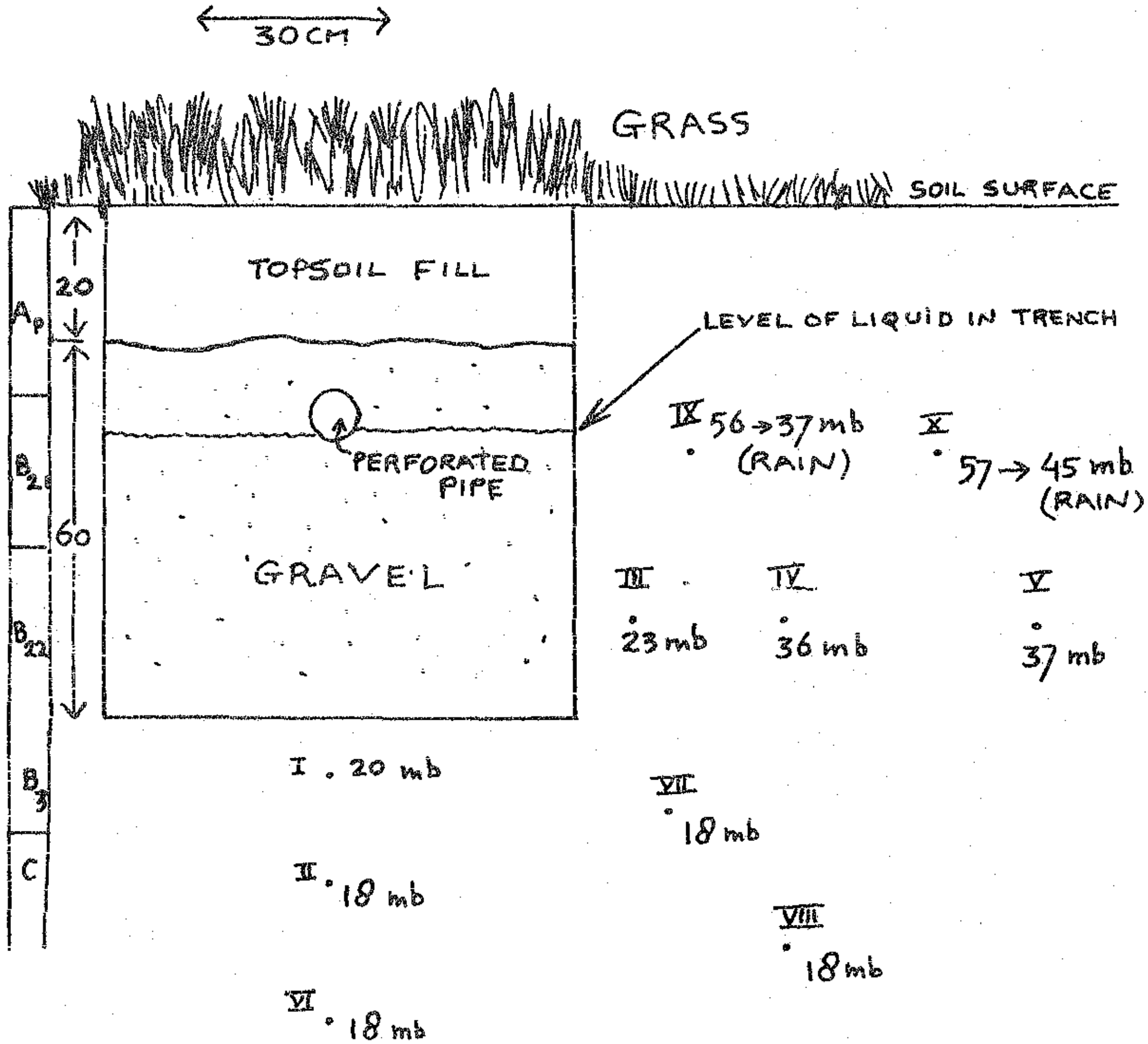
It is interesting to note that the approximate Streptococcus numbers in fresh human feces is about 3×10^6 per gram (Kenner et al., 1960). Thus the range of counts in the sewage here is indicative of very little survival. This too implies that a great die-off of Streptococci must be occurring from the time the effluent reaches the tank till it moves into the absorption field (tank retention times have been estimated at 1-3 days depending upon size of the family or facility served, size of tank, amount of water used, etc.).

Photo 3.4.2b Absorption field in Plainfield loamy sand at Friendship.
The location of the seepage beds, which were filled with effluent, is clearly marked by lush growth of grasses (G). An excavation (E) was made next to the middle bed for purposes of sampling and measurement of soil moisture tensions (see diagram of system, Figure 3.4.2).

SOIL ABSORPTION SYSTEM IN PLAINFIELD LOAMY SAND (Friendship, Wis)



Top view of seepage bed



Cross section of trench* with tensiometer readings

Fig. 3.4.2.

3.4.2. System at Friendship, Wisconsin

3.4.2.1. Introduction

This system was built eleven years ago. Investigations were made in September, 1970. Despite very high loading rates, estimated to average about 600 gallons per day, there had been no problems with this system. A top view and cross section of the system are shown in Fig. 3.4.2. Abundant growth of grasses above the trenches (Photo 3.4.2b) indicated subirrigation with effluent. The distribution box of the system (Photo 3.4.2a) was of special construction, with half-inch vertical spacings of stepped outlets to the three seepage beds. A pit was dug next to the central bed in the three-bed system after it was observed in the distribution box that effluent was standing in all beds. Soil moisture tensions were measured around the bed (Photo 3.4.2c). Physical analyses of this pedon and crust test results are similar to those of the Hancock pedon (Section 3.4.1). Two soil percolation tests were made at 80 cm depth in the pedon, and a representative profile was described. Samples were taken from the soil around the trench for microbiological analyses.

3.4.2.2. Results and discussion

The percolation rate, determined by the State Percolation Test, was 2 min/inch ($\approx$1800 cm/day). Real flow rates from the bed into the surrounding soil must be much lower to account for the presence of liquid in the trench at a loading rate of 600 gallons/day. The total bottom area of the three beds, (all filled with effluent to a level of about 40 cm) was 87 m^2. Sidewalls provide an additional absorptive area of $180 \times 0.4 = 72$ m^2. Soil moisture tensions were 20 mbar below the bed, and increased from 23 to 36 mbar at the sides. K at 20 mb is 2.5 cm/day (Fig. 3.4.1a). Vertical infiltration can then be estimated at 540 gallons/day (vertical gradient is unity).

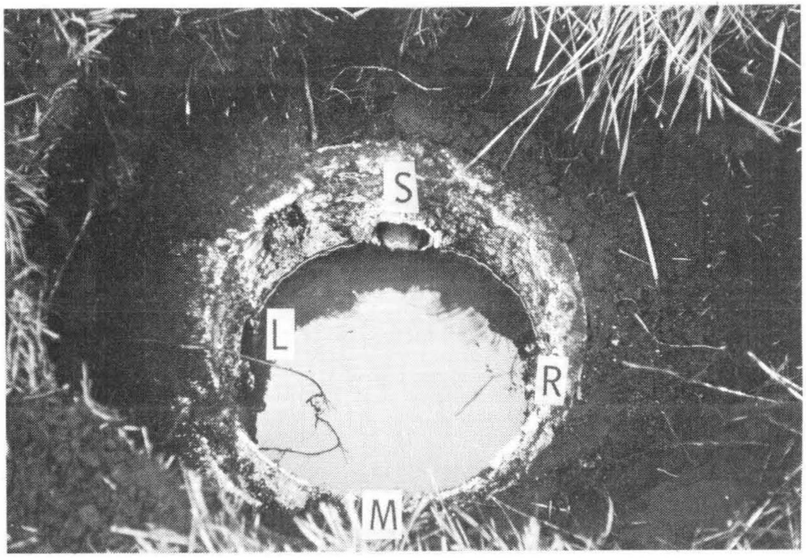


Photo 3.4.2b View of distribution box with lid removed, showing inlet from septic tank (S). Three pipes of which L is clearly visible lead to the three legs of the seepage field. These pipes leave the box at different levels: pipe (L) is one inch higher than M, which is one inch higher than R.

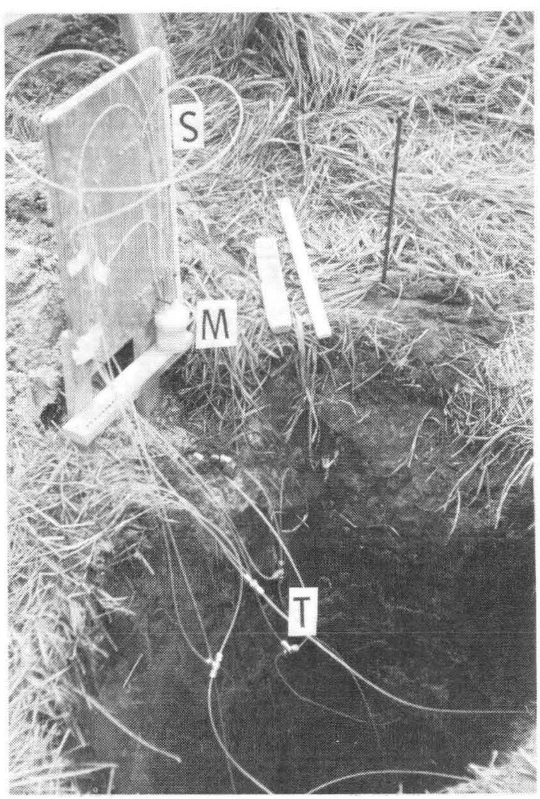


FIG.3.4.2c

Apparatus for field measurement of soil moisture tensions (see also, Figures 2.3.3d and e). The 1/8 inch plastic tubes (T) are filled with water and connect pencil-sized tensimeters (inserted into the soil at points 1, 2 and 3) to mercury cup M. Moisture tension in the soil is determined by reading the equilibrium level of the mercury column in the tube along the calibrated scale, S (see Section 2.5).

Table 3.4.2. Bacteriological analysis of effluent and soil samples around the seepage bed.

Sample number and location+	Bacterial Counts / gram		
	EMB*	PCA	m
I	3×10^2	5×10^6	0
II	1×10^2	220×10^6	0
III	$<10^2$ >10	10^6 many molds	0
IV	$<10^2$ >10	1.7×10^6	0
Control	$<10^2$ >10	5×10^5	0
Distribution Box	46×10^3 (31×10^3 fecal)	27×10^6	0

*no fecal coliforms present unless otherwise indicated

+see Fig. 3.4.2.

m= m-ENTEROCOCCUS AgAr count

Horizontal potential gradients are small (about 1/3). Flow is estimated at 125 gallons/day. Combined vertical and horizontal infiltration is therefore about equal to estimated loading. Microbiological data (Table 3.4.2) show a strong decrease in EMB count as a function of distance from the seepage bed. Numbers similar to those in a control sample, taken several meters away from the trenches, were counted in samples within 50 cm from the system. These figures show that in this particular soil coliform content of the trench effluent is significantly reduced after percolation through a relatively small volume of soil. This is achieved because of the impedance by an organic crust at the interface of soil and gravelbed, inducing a soil moisture tension of 20 mb in the underlying soil, even though the bed is filled with effluent. Resulting slow movement of effluent into the unsaturated, aerated soil is favorable for purification. Moisture retention data presented in Fig. 3.4.1b shows that 15% of the soil volume is filled with air, at 20 mb suction. The composition of this air is unknown. However, only large pores are filled with air at such a suction, and it can be hypothesized that considerable atmospheric oxygen diffuses through these pores. Distances of diffusion are relatively small in this superficial system. Accumulation of organic compounds resulting from anaerobic processes will be limited in such a relatively aerobic soil environment (Section 3.2.5). As a result, crust development is also limited and only a moderate impedance develops. This system is very interesting in that it does not need a dosing cycle to function properly even when ponding effluent persists in the trenches.

3.5. Evaluation of the Wisconsin State Percolation Test Procedure

3.5.1. Introduction

Suitability of a site for the construction of a septic tank disposal system is determined on the basis of slope of the area, level of the water table, depth to bedrock, if any, and a mandatory percolation test (State Board of Health, 1969), (see Section 2.1). The percolation rate is expressed in the number of minutes required for the water to fall one inch. This value can be translated into the more common physical units of cm per day by calculating the ratio between 3600 and the number of minutes per inch. Estimates of required dimensions of the future system are based on the percolation rate, if less than 60 minutes per inch, and predicted loading rates of the system. These estimates can be reliable only if 1) the test procedure itself gives respresentative and reproducible results for each location, and 2) if such results apply to the real physical conditions in and around an operating disposal system. These two aspects will be considered separately in the following.

3.5.2. Variability of test results; comparison with methods

The method to determine the percolation rate (State Board of Health, 1969, Section 2.1) has been studied by many authors (see review by McGauhey and Krone, 1967). Correlations of percolation tests with soil properties were studied by Derr et al.,(1969). They report results of several thousands of tests, made in Pennsylvania. At any given site 3 to 6 tests were made. The coefficient of variability for replicate tests on one site varied from 0-253%, with an average of 73%. Variation between sites was slightly higher than variation within a site. The percolation rate was possitively correlated with the clay content of the subsoil and the drainage class. The authors concluded that the very high variability of results makes the test quite unreliable. Mokma (1965) demonstrated considerable seasonal variations in test results.

Results of the present study are reported below with respect to:

1. Range of variability of test results.
2. The seasonal variation of percolation test results.
3. A comparison of results obtained by the official test procedure (which allows a falling water level) with results obtained by a procedure in which a constant water level is maintained in the test hole.
4. A comparison of the percolation test results with K-values determined by the Bouwer double tube procedure.

Investigations were made in seven soil horizons, as indicated in Table 3.5.2 and corresponding figures. Variation of test results is expressed as the coefficient of variability, that gives the standard deviation S of test results as a percentage of the average $\left(S = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}\right)$. At each site the individual test holes were made within an area of $25m^2$ ($\approx$ 225 sq. ft.) The distance between holes was always more than 1.2 m (4 feet).

The infiltration curves, as determined in the field (Fig. 3.5.2.1) are given for the official State Percolation Test Procedure (SPT) and for the Constant-Level Percolation Test procedure (CLPT) (Figures 3.5.2.3 through 3.5.2.23). Data derived from these curves are presented in Table 3.5.2 for 7 pedons. The SPT data of the 1970 field season include the rates as measured after 2, 4, 6 or 8 hours of wetting on the second day. The value observed after $3\frac{1}{2}$ to 4 hours on that day is taken as the official percolation rate. Infiltration rates were also recorded during the "soaking period" of the previous ("the first") day. SPT data for the 1969 field season (Bouma et al., 1970) were calculated from the rate of fall of the water level after 4 hours on the second day, as directed in the test procedure.

The coefficient of variability (CV) was calculated for replicate SPT measurements at every location for each field season separately and for all values combined. The Constant Level Percolation Test (CLPT) was done in 1970 only. CV values for this test, therefore, only apply to the spring season of 1970.

CV values were also calculated for each individual hole used for a SPT or CLPT determination, expressing the variability of readings on the second day after 2, 4, 6 and 8 hours. This CV value, calculated only for the 1970 data, made possible an evaluation of the significance of the required arbitrary four hour period of measurement during the second day. Hydraulic conductivities (K) measured with the Bouwer double tube apparatus in both summer and fall of 1969 and the spring of 1970 are reported here for each horizon, along with their CV values.

The seven horizons represented in Table 3.5.2 are referred to by number in the text, Viz. No. 2, No. 5, etc.

The following conclusions can be drawn from the assembled data:

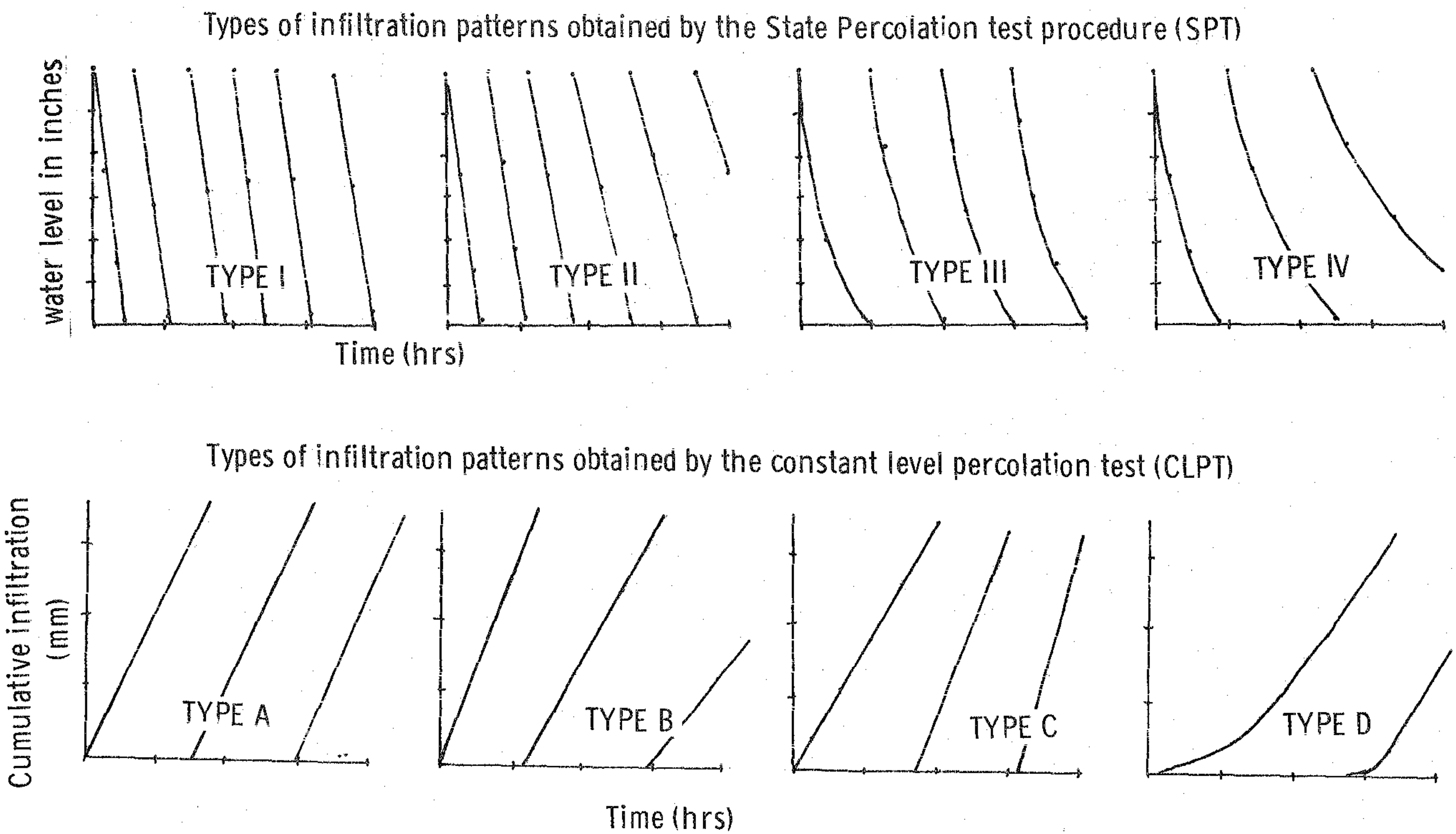
(1) The CV values of the State Percolation Tests in the summer and fall of 1969 vary between 10% (No. 5) and 100% (No. 2). The average was 50%. When all values for each horizon are combined, the range is 40% (no. 4) to 90% (No. 2), with an average of 57%. This is a high value although still lower than the 73% reported by Derr et al. (1969). It means that an average percolation rate of, for example, 20 min/inch has to be read as being between 31 and 9 min/inch with a probability of 68%; so there is a chance of one in three that values occur even outside this range. All horizons included in our experiments were in relatively homogeneous well drained materials, except for the B3 of the St. Charles-Batavia silt loam (No. 2). This horizon was close to the interface between leached loess and glacial till, which may account for its quite variable behaviour. But even when this horizon is excluded, CV is still no less

50%. The greater part of this high variability is due to the heterogenity of the natural soil. Some of it, however, is the result of the measurement procedure (see item 3, below).

(2) Seasonal differences in SPT results do not show any consistent pattern. Similar rates were measured in spring and late summer in No. 1; higher rates in spring in No's 3, 4, and 6 and lower in No's 2 and 5. Differences do not correspond with the initial soil moisture contents before soaking. For example, in the spring the rate was higher in No. 3, although the initial moisture content of the horizon was highest in that season. The rate in No. 2 was lower in spring, although the initial moisture content was lowest then. Except for the initial soil moisture content, many other factors may contribute to the observed differences: better cleaning the bottom of the hole with a new hole cleaner in 1970 as compared with the work in 1969; the method of measurement of the water level; the way the hole was filled with water after each six-inch fall, etc. These results do not confirm those of Mokma (1969) who reported relatively low values in spring, due to the relatively high water content of the soil which reduced the hydraulic gradient (see point 4). Presoaking, during the first day of the test procedure, has apparently substantially reduced differences in hydraulic conditions in different seasons. The percolation rates observed during the first day of soaking, are often lower than those measured on the second day (see data for Nos. 1, 3 and 4 in Table 3.5.2).

(3) The variability of the Constant-Level Percolation Tests (CLPT) is lower than that of the regular percolation test. The average CV for CLPT tests in spring 1970 was 34%, whereas SPT results in the same period had a CV of 50%. A constant water level is maintained in the CLPT at 6 inches above the gravel. Any variability in infiltration with time can

Fig. 3.5.2.1.



Types of infiltration patterns obtained by the State Percolation test procedure (SPT)
water level in inches
TYPE I
TYPE II
TYPE III
TYPE IV
Time (hrs)
Types of infiltration patterns obtained by the constant level percolation test (CLPT)
Cumulative infiltration (mm)
TYPE A
TYPE B
TYPE C
TYPE D
Time (hrs)

therefore be attributed to changes in soil structure and hydraulic conditions around the test hole. The State Percolation Test, on the contrary, measures the rate of fall of the water level from the 6" level downward to the gravel. As the water level moves down, the area available for horizontal flow through the sidewall of the hole decreases. This may lead to a marked decrease of infiltration during each run.

Four different infiltration patterns of the SPT can be distinguished (Bouma et al., 1970) and are illustrated in the upper part of Fig. 3.5.2.1. Type I shows a constant infiltration rate at all times. Type II shows a decrease of infiltration with time, due to other factors than change in water level, as indicated by the constant slope of each separate line. Types III and IV, on the contrary, show rate decreases related to the decreasing level of the water, reflected in the change in the slope of each line during each separate run. Variation in the percolation test results of these two types is caused by the method of measurement as well as by soil factors.

The lower part of the Figure 3.5.2.2. presents four infiltration patterns of the CLPT, numbered A through D.

Type A represents a constant steady infiltration rate in a soil that was moist throughout before the test began. Type B shows a decline of infiltration rate resulting from increasing remoteness of the wetting front, and decreasing potential gradients in an originally rather dry soil. Type C shows an increase of infiltration with time, possibly as a result of gradual removal of air from soil pores by solution of air in water. Type D shows a clear increase during a single run, whereas in the other types each run had a constant rate.

CROSS SECTIONAL DIAGRAMS ILLUSTRATING THREE FIELD TESTS

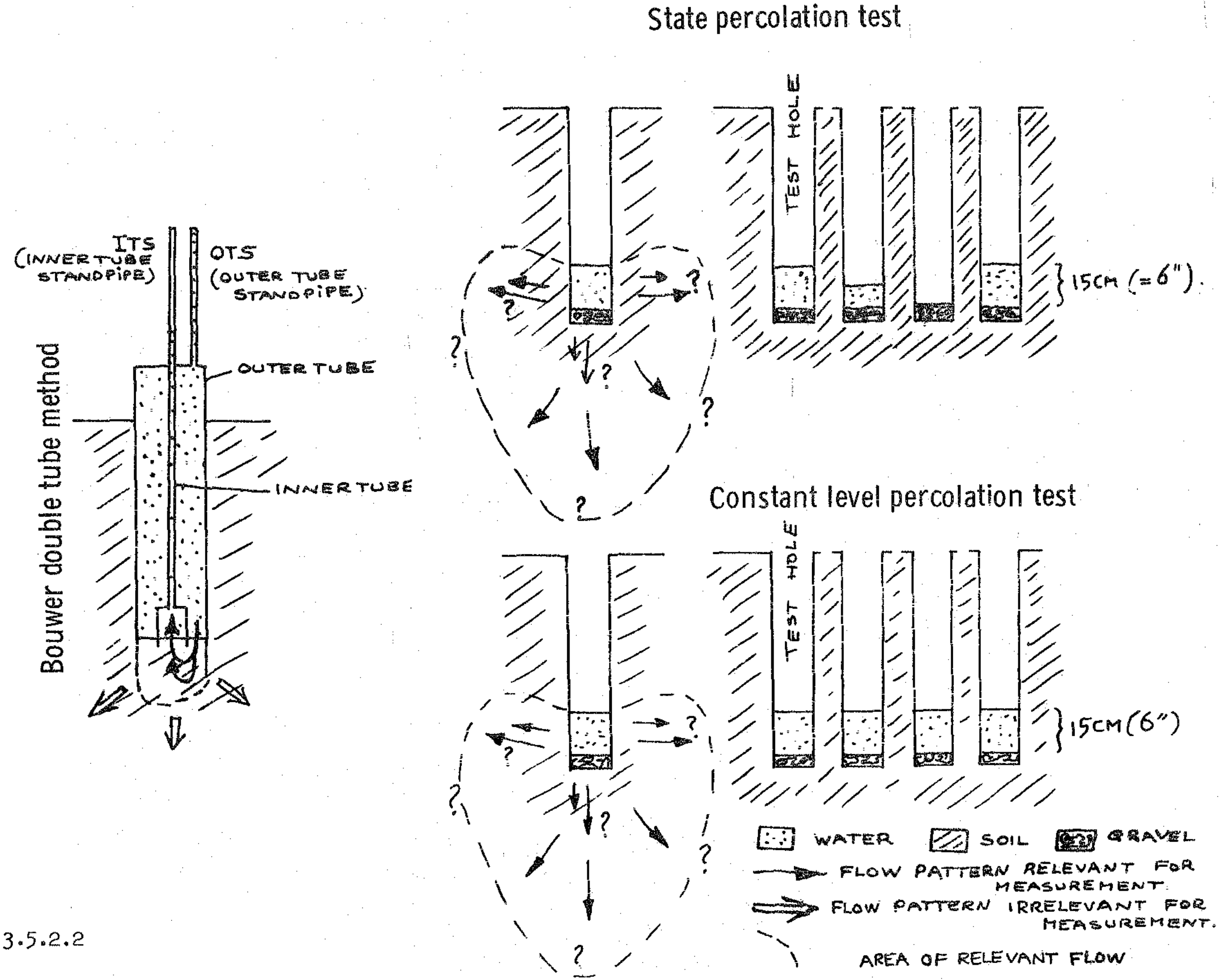


Fig. 3.5.2.2

Changes in infiltration rate can also occur because of proximity of the test volume to the interface between finer textured material above a coarse material.

The observed difference in CV between SPT and CLPT test results can be explained, therefore, since most SPT measurements exhibit the properties of the Type III curve, which are absent in curves A through D. To further explore the variability of SPT measurements, percolation rates (spring, 1970) for individual test holes have been calculated not only after a 4 hour period as required, but also after 2, 6 and 8 hours. Generally a decrease in the percolation rate with time is to be expected, since wetting will lead to a decrease of suction gradients in the soil and processes of swelling may reduce infiltration. However, attention should be given only to decreases caused by hydraulic and soil factors, which are relevant, not to those caused by the measurement procedure itself. In individual SPT holes the CV values varied between 70% (No. 5) and 17% (No. 4), with an average value of 44%. CV values for individual CLPT holes varied between 0 (No. 1 and 2) and 16% (No. 3) with an average of 6%. Again, the observed differences have to be attributed to the measurement procedure followed in the State Percolation Test, that adds an estimated 15% to its CV value (see page 85). Maintaining a constant water level in the test hole, therefore, reduced the variability of results substantially.

(4) Hydraulic conductivity (K) values measured with the Bouwer Double Tube Method in a confined volume of soil of about 1,000 cm^3 (see Fig. 3.5.2.2.) have a significantly lower CV (26%) than the other methods. K values are well defined soil physical constants that can be used in physical models of moisture flow (see Chapter 5). An infiltration rate such as that measured by the SPT cannot be considered as a physical constant because

it is affected by variable boundary conditions in a large, undefined, volume of soil. Flow rates can be calculated if K values for both saturated and unsaturated soil are known, as well as the hydraulic gradients in the soil material. The gradients are measured with tensiometers

Investigation of operating systems (Sections 3.1-3.5) has proved that the soil around septic tank seepage trenches is not saturated due to presence of crusts of organic material on the trench surfaces. This implies that the liquid moves much more slowly into the soil than would be indicated by the saturated hydraulic conductivity. The new crust test (see Chapter 2.3) yields the hydraulic conductivity (K) as a function of moisture content. Using such K values, flow rates can be predicted for unsaturated soil in accordance with suction gradients.

3.5.3. Interpretation of Percolation Test Results

The infiltration rates measured with the State Percolation Test are actually all relatively high. The limiting value of 60 min/inch (=60 cm/day) still represents a considerable volume: In one day, 150 gallons of liquid would percolate into an area of 1 m^2 ($\approx$10 sq. ft.). An absorption field of only 20 square feet in an uncrusted soil with K = 60 cm/day, would be sufficiently large to handle 300 gallons per day, the average effluent load for a family of four. In sandy soils an even smaller field would be adequate. A soil with a percolation rate of 2 min/inch (=1800 cm/day) would need an absorptive area of only 700 cm^2 (that is less than one square feet) to handle 300 gallons per day. Practical experience has shown that things do not work out this way. As a consequence, the State Code (State Board of Health, 1968) requires a minimum absorption area of 50-85 square feet in soils with a percolation rate less than 3 min/inch. Some systems fail nevertheless. Percolation test results, therefore, do not predict the infiltration rates as they occur

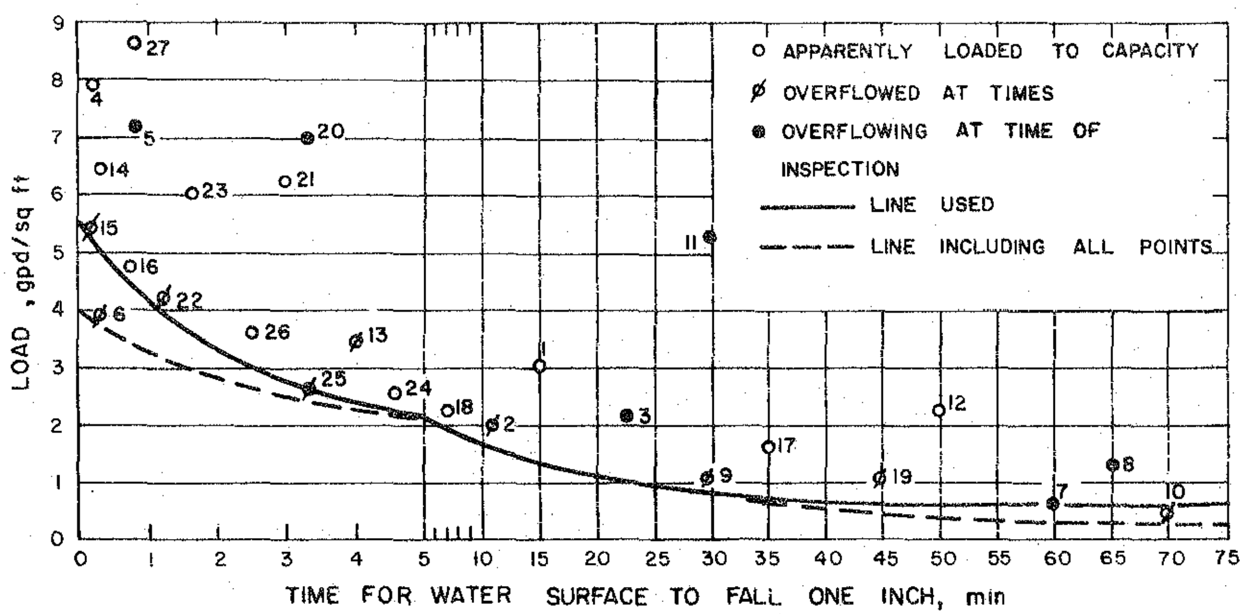


FIGURE 3.5.3 RELATIONSHIP OF TILE FIELD LOADING RATES TO PERCOLATION TEST RATES (from McGauhey and Krone, 1967).

from seepage trenches. The real rates are much lower than those given by the test. This has been known for a long time (McGauhey and Krone, 1967) but the test has continually been applied since the nineteen twenties primarily because of lack of a better one, and also because of its usefulness in ranking different soils according to their relative capacities to transmit liquid. The great reduction in the soils infiltrative capacity by organic crusts on the walls of the trench (McGauhey and Krone, 1967) has been deëmphasized if not ignored. Since it has been quite obvious that real infiltration rates in disposal field are much lower than rates measured by the SPT, empirical research and theorizing have been done to determine "factors" of reduction. Ludwig et al. (1949; see McGauhey and Krone, 1967) suggested the use of a "factor" of 20. That is to say, the amount of sewage effluent which may be leached away in a soil was estimated to be approximately one-twentieth of the amount of clear water that could seep through the same soil. Kiker (1953) stated that soils in Florida would absorb 40 times as much water as effluent from settled sewage. Percolation rates have also been empirically interpreted in terms of loading rates. Federik (1952) introduced the formula:

$$Q = 5/\sqrt{t}$$

where Q = the loading rate in gallons per day per square feet in a tile field and t = percolation rate in min/per inch. Kiber (1953) introduced:

$$G = 29/t + 6.24$$

where G = Q of the previous formula.

In the original approach of Ryon, who introduced the test in 1928, percolation rates and loading rates were measured at several sites. Those values were plotted in a figure (see Fig. 3.5.3. from McGauhey and Krone) and a line was drawn arbitrarily separating systems where all applied liquid was absorbed by the soil from those where overflow occurred.

Criteria, derived from this type of graph, are still being used and form the basis of current criteria for determining suitability of soils for private waste disposal systems (State Board of Health, 1968). According to this approach the percolation rate is reduced by a factor varying from 20 to 2500, depending on the location of the system on the chart.

Data reported above show that the interpretation of percolation test results is empirical. As pointed out in Section 3.5.2. (Point 4), knowledge of the hydraulic conductivity characteristics will make it possible to calculate the moisture movement as a function of crust resistance. The study of the seepage bed at the Poultry Farm (Arlington)(Chapter 3.2) proved that crust resistance is not a constant, but varies as a function of the dosing rate. This points to an oversimplification in the State Percolation Test. There is no fixed permeability value, whether for saturated or unsaturated soil, that will sufficiently characterize a soil system around a seepage bed. Rather, there is a possible range of permeability values. Loading rates, pretreatment and dosing will determine at what rate, lying within a certain range, the soil absorbs the liquid at any given time. A second oversimplification of the STP is its sole emphasis on hydraulics. The problem of liquid waste disposal is also a problem of disposal of nutrients (NO_3, P) and harmful microorganisms. Therefore, an adequate study of the problem of disposal of liquid waste of septic systems through soil absorption can only be made by considering all these interrelated factors together. Results of this type of study were reported in Chapter 3.1-3.5.

3.5.4. Conclusion

The State Percolation Test gives highly variable results (the average coefficient of variability, CV, was 50%). Maintaining a constant water level in the test hole can reduce variability to an estimated 35%. Such infiltration rates, however, are still not physical constants, in the sense that hydraulic conductivity (K) values are, and cannot be used therefore in physical flow-models. In this study K values for saturated soil were measured with the Bouwer Double Tube apparatus. These measurements had a relatively low CV of 25%. However, experimental data shows that flow from seepage trenches occurs mainly in unsaturated soil. Therefore, unsaturated K values, were measured in the field with the newly developed crust test, and were found to be essential to model and to understand the flow of liquid from septic tank disposal trenches. No single fixed conductivity value applies to a flow system (as is assumed in the State Percolation Test) but rather any of a number of values constituting a characteristic range. Management of a given liquid waste disposal system will determine which K value in this range applies to the actual hydraulic condition. Finally, any test of site suitability should not be restricted to movement of liquid only but should consider problems of chemical and biological pollution as well.

Table 3.5.2.* Results of percolation tests of seven soil horizons.

	No. of holes	Perc. rate first day 2hr	4hr	6hr	Perc. rate sec. day 2hr	4hr	6hr	Perc. rate third day 2hr	4hr	6hr	CV, second day (%)	CV, 1969-70 (%)
St. Charles-Batavia silt loam (Charmany farm).												
1. Horizon: B21t (60 cm depth) Initial moisture 1969: 0.6b; 1970: 0.1b (est.)												
SPT July 1969	6	---	---	---	---	22	---	---		---	36	41
SPT April 1970	3	15	14	20	14	22	24	---	---	---	40	
CLPT April 1970	3	15	15	---	10	10	10	9	9	---	35	
Individual test holes April 1970-SPT												
No. 7		14	11	16	12	18	24				30	
No. 8		16	8	17	15	15	27				40 } 40	
No. 9		16	22	27	15	32	22				53	
April 1970-CLPT											0	
Bouwer K: 57 cm/day (63 min./inch) 4 meas.												25
2. Horizon: B31 (120 cm depth) Initial moisture tension 1969: 0.3b; 1970: 0.5b (est.)												
SPT July 1969	6					45					100	90
SPT April 1970	3	38	54	57	44	87	89				100	
CLPT April 1970	3	80	80	80	76	76	76				90	
Individual test holes April 1970-SPT												
No. 10		14	12	20	11	13	19				30	
No. 11		20	30	30	40	128	90				73 } 50	
No. 12		80	120	120	80	120	200				48	
April 1970-CLPT											0	
Bouwer K: 22 cm/day (160 min./inch) 4 meas.												25

*All percolation rates are given in min./inch, unless otherwise stated.

Table 3.5.2. (continued).

	No. of holes	Perc. rate first day 2hr	4hr	6hr	Perc. rate sec. day 2hr	4hr	6hr	Perc. rate third day 2hr	4hr	6hr	CV, second day (%)	CV, 1969-70 (%)
Plano silt loam (Mandt farm).												
3. Horizon: B21t (50 cm depth) Initial moisture tension: 1969: 0.1b; 1970: 0.03b (est.)												
SPT July 1969	6	---	---	---	---	28	---	---	---	---	35	45
SPT May 1970	3	7	9	---	10	11	11	---	---	---	15	
CLPT May 1970	3	3	3	---	6	6	5	3	---	---	10	
Individual test holes												
May 1970-SPT												
No. 7	7	8	---		7	11	11				22	
No. 8	7	11	---		16	12	12				20 } 23	
No. 9	7	8	---		6	9	10				26	
-CLPT												
No. 2	2	---	---		6	8	5	3	---	---	25	
No. 5	4	---	---		6	6	6	6	9	9	0 } 16	
No. 6	2	9	---		6	4	4	4	4	---	22	
Bouwer K: 28 cm/day (120 min./inch)												25
4. Horizon: B31 (20 cm depth) Initial moisture tension 1969: 0.1b; 1970: 0.1b (est.)												
SPT July 1969	6					33					20	40
SPT May 1970	3	8	6	---	15	16	13	---	---	---	48	
CLPT May 1970	3	5	---	---	12	10	10	19	8	---	25	
Individual test holes												
May 1970-SPT												
No. 10	7	8	---		23	21	18				12	
No. 11	10	5	---		13	19	12				17 } 17	
No. 12	6	7	---		8	9	10				11	
-CLPT												
No. 1	10	---	---		25	19	19	40	15	---	16	
No. 3	2	---	---		6	5	---	10	5	---	15 } 15	
No. 4	4	---	---		6	5	---	6	5	---	15	
Bouwer K: 11 cm/day (330 min./inch)												25

	No. of holes	Perc. rate first day 2hr	4hr	6hr	Perc. rate sec. day 2hr	4hr	6hr	8hr	CV, second day (%)	CV, 1969-70 (%).
Tama silt loam (Platteville) virgin site.										
5. Horizon: B2t (20 cm depth) Initial moisture tension 1969: 0.3b; 1970: 0.1b (est.)										
SPT Oct. 1969	2	---	---	---	---	6	---	---	10	
SPT May 1970	3	---	---	---	9	12	16	42	70	82
CLPT May 1970	3	5	8	6	6	6	6	---	30	
Individual test holes May 1970-SPT										
No. 8				15	14	30	80	90		
No. 10				7	11	10	23	54	} 70	
No. 11				6	10	9	23	62		
-CLPT										
No. 1		6	10	5	6	6	6	---	0	
No. 6		6	9	9	8	8	8	---	0 } 5	
No. 4		4	4	4	5	4	4	---	16	
Bouwer K: 95 cm/day (38 min./inch) 3 meas.										30
Tama silt loam (Platteville) cultivated site.										
6. Horizon: B31 (80 cm depth) Initial moisture tension 1969: 5b.; 1970: 1b (est.)										
SPT Oct. 1969	2	---	---	---	---	38	---	---	40	45
SPT May 1970	3	---	---	---	14	21	42	17	25	
CLPT May 1970	3	1	3	5	8	8	8	---	12	
Individual test holes May 1970-SPT										
No. 9		---	---	---	11	24	13	16	44	
No. 7		---	---	---	20	15	96	16	100 } 60	
No. 12		---	---	---	10	24	16	19	40	
-CLPT										
No. 2		1	1	4	8	8	9	---	8	
No. 5		2	6	7	9	9	9	---	0 } 3	
No. 6		1	2	4	7	7	7	---	0	
Bouwer K: 27 cm/day (130 min./inch)										30

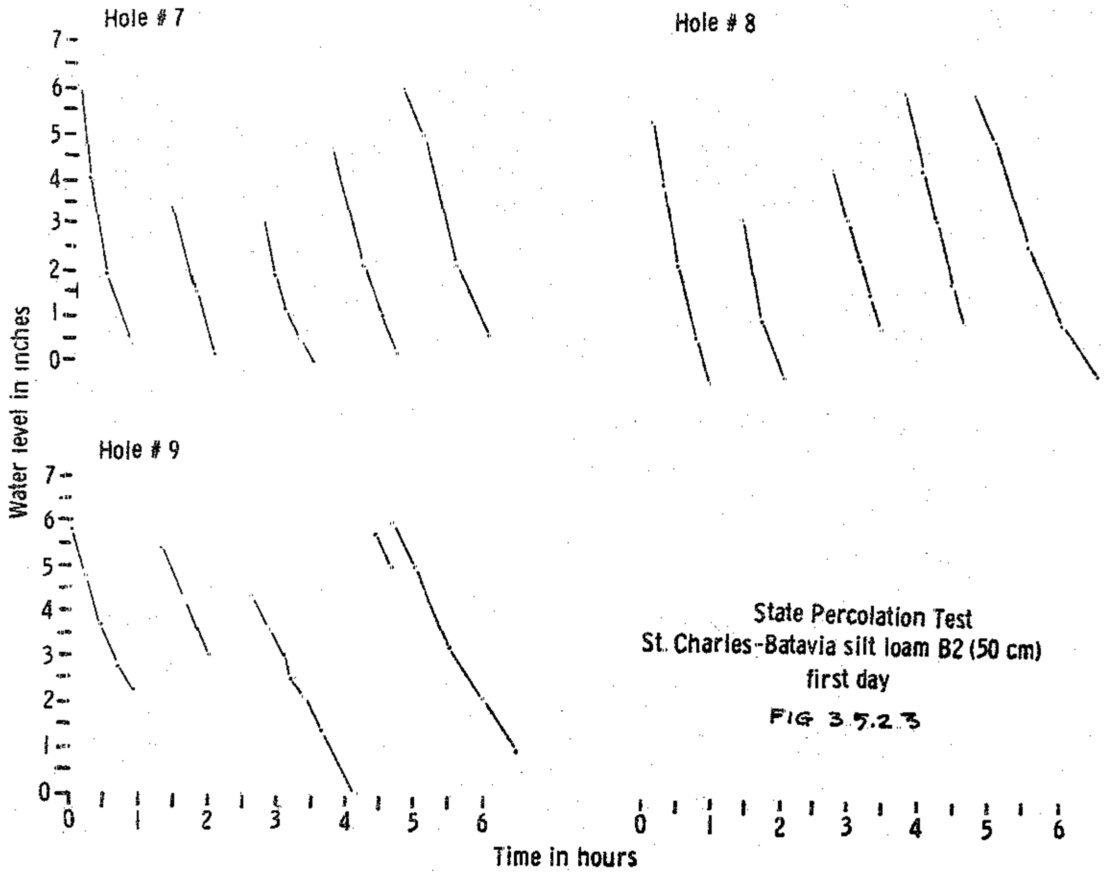
Table 3.5.2. (continued).

	No. of holes	Perc. rate second day 2hr	Perc. rate second day 4hr	CV, second day (%)	CV (of both# sites), 1970 (%)
Stony sandy loam till (Arlington Experimental farm).					
7. At 90 cm depth in a Saybrook silt loam. Initial moisture tension: 0.1b.					
SPT July 70 (Poultry)	3	4	4	35	60
SPT July 70 (Dairy)	3	3	3	60	
PLTC July 70 (Poultry)	1	4	3		20*
PLTC July 70 (Dairy)	1	5	4		
Individual test holes					
SPT Poultry					
	No. 1	5	5		
	No. 2	6	6	0	
	No. 3	1	1		
SPT Dairy					
	No. 1	1	1		
	No. 2	3	3	0	
	No. 3	5	5		
PLTC Poultry		4	3	20	17
PLTC Dairy		5	4	15	

Bouwer K: No measurement possible because of stones. From crust test procedure:

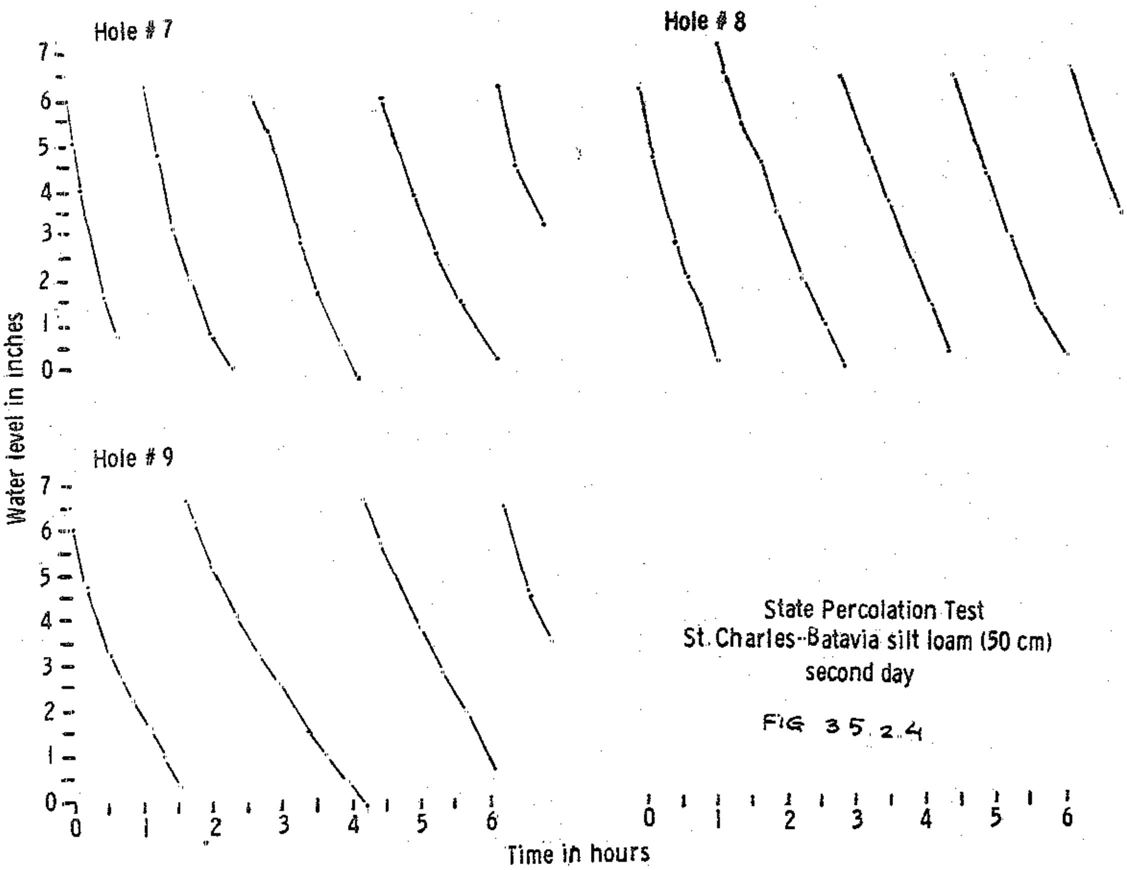
$$K_{sat} = 80 \text{ cm/day } (45 \text{ min./inch})$$

*Amount of replicates is too low here.
#Poultry Farm and Dairy Center, Arlington Farms, Wisconsin Agr. Exp. Sta.



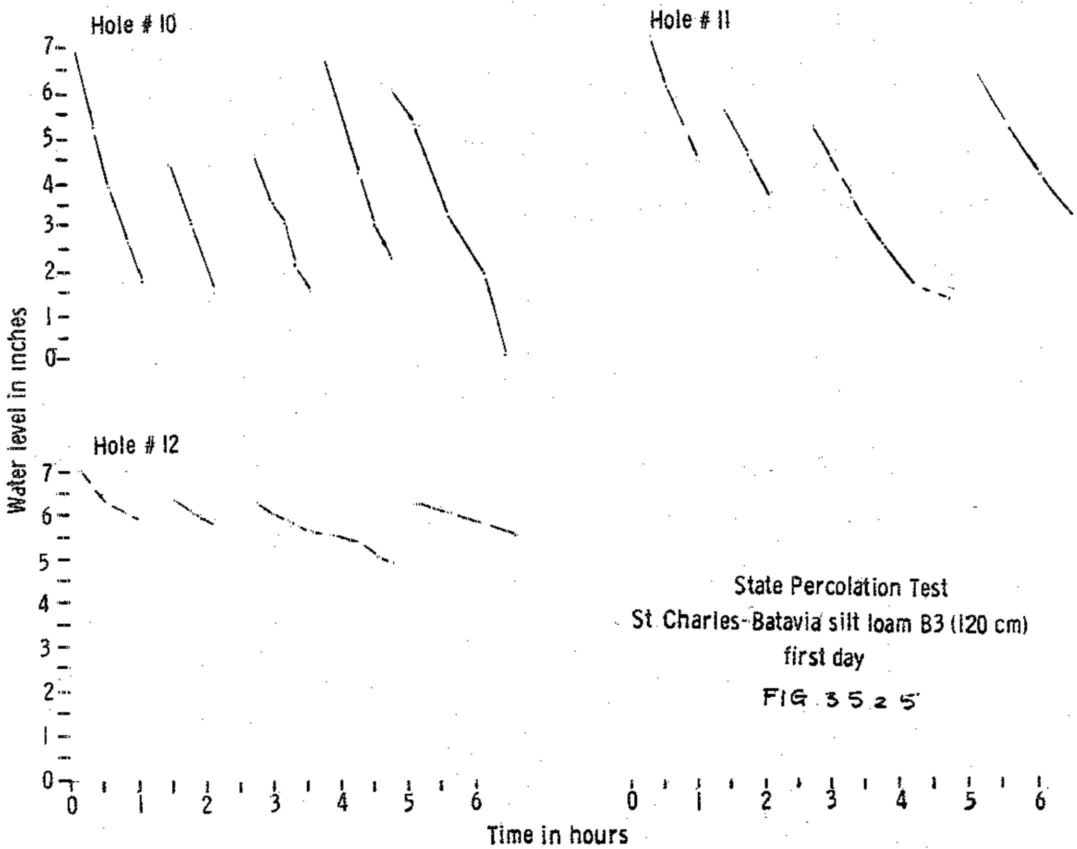
State Percolation Test
St. Charles-Batavia silt loam B2 (50 cm)
first day

FIG 3.5.2.3

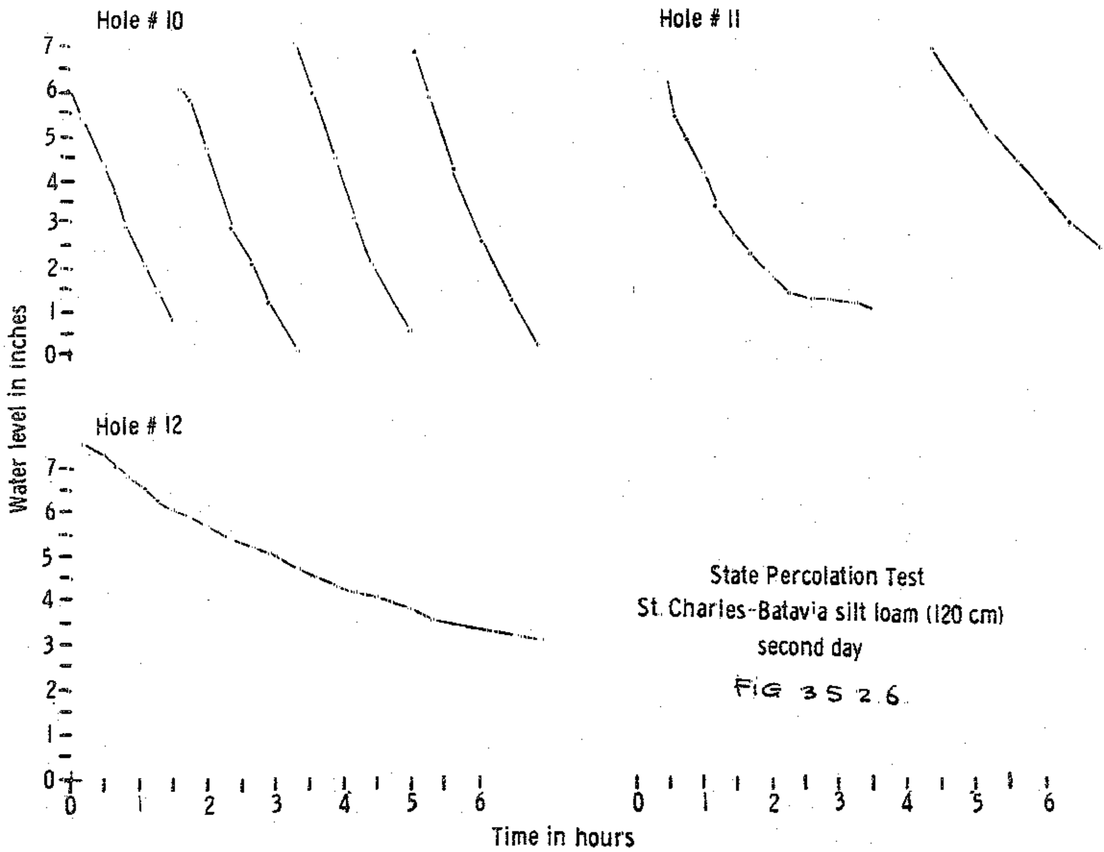


State Percolation Test
St. Charles-Batavia silt loam (50 cm)
second day

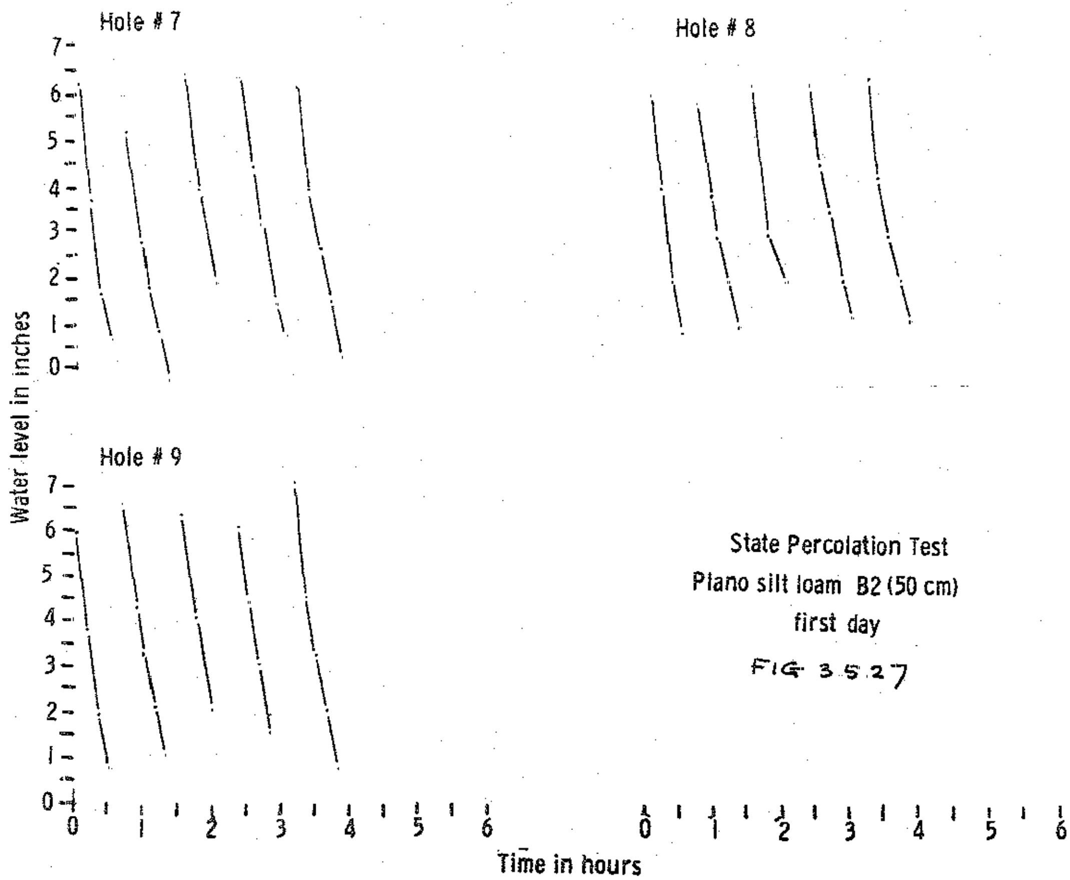
FIG 3.5.2.4



State Percolation Test
St. Charles-Batavia silt loam B3 (120 cm)
first day
FIG 35 2 5

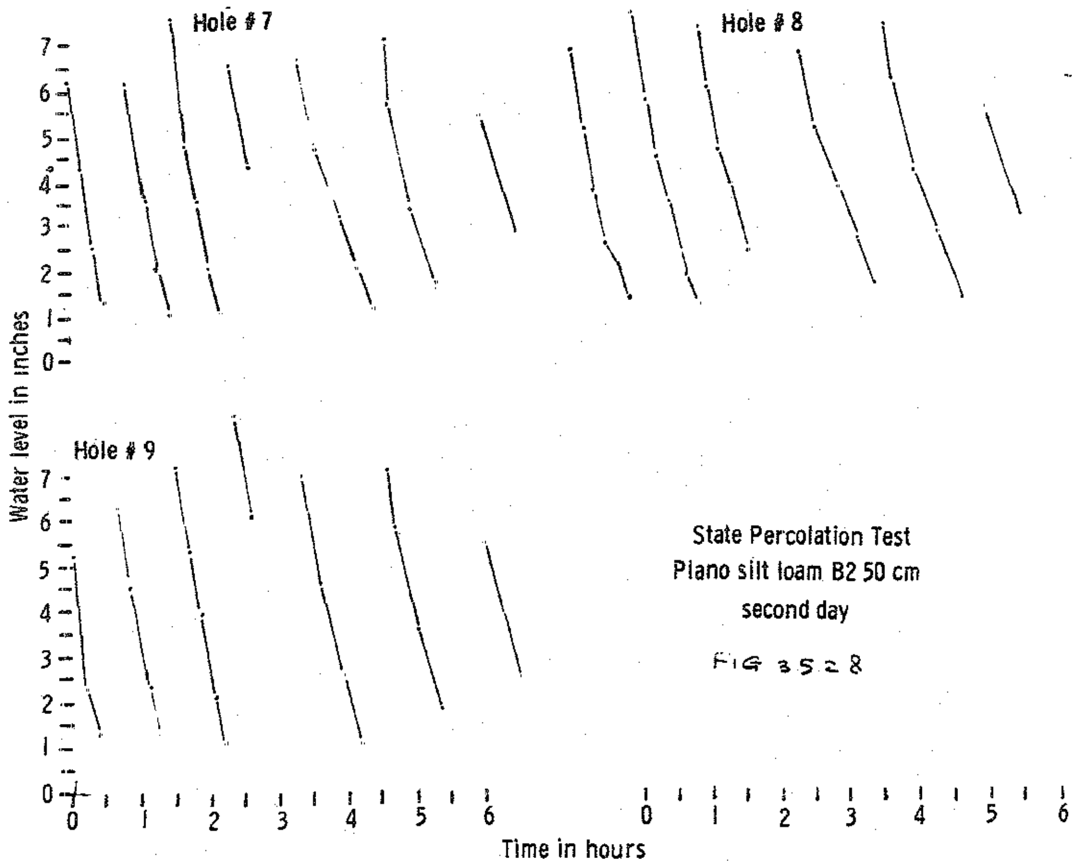


State Percolation Test
St. Charles-Batavia silt loam (120 cm)
second day
FIG 35 2 6



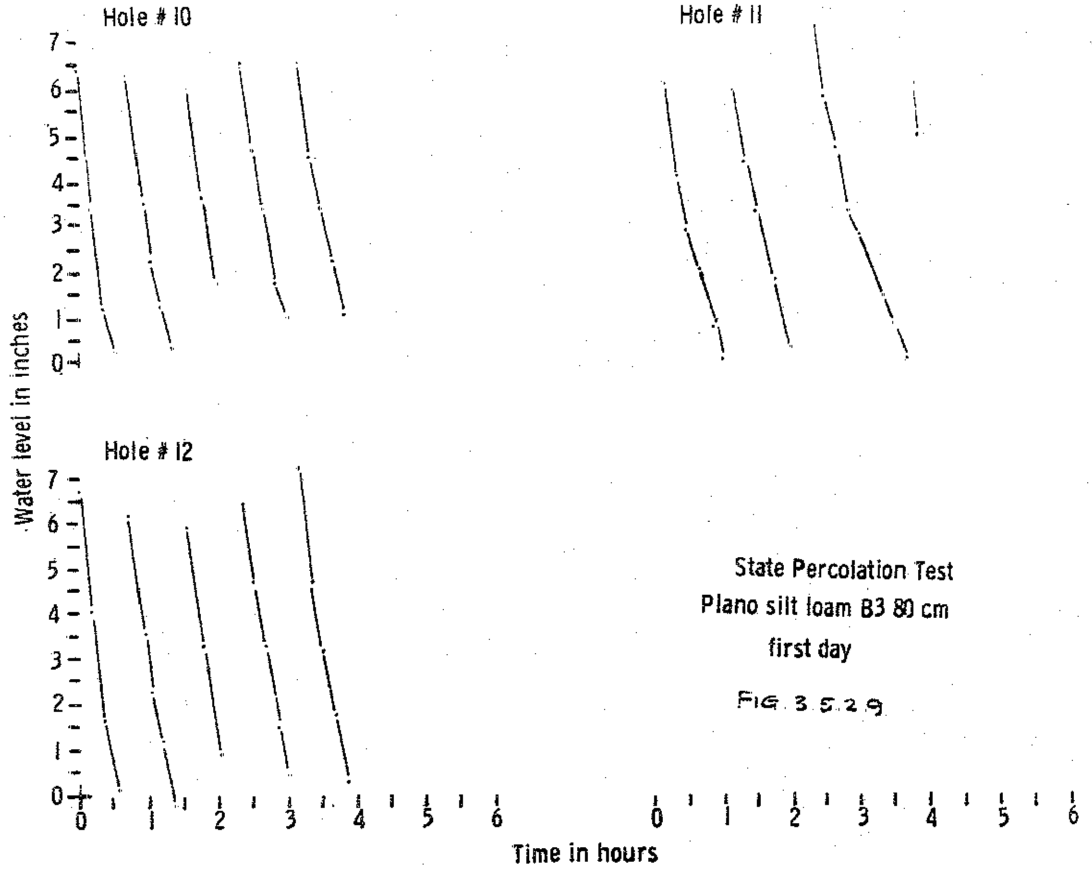
State Percolation Test
Plano silt loam B2 (50 cm)
first day

FIG 3.5.27



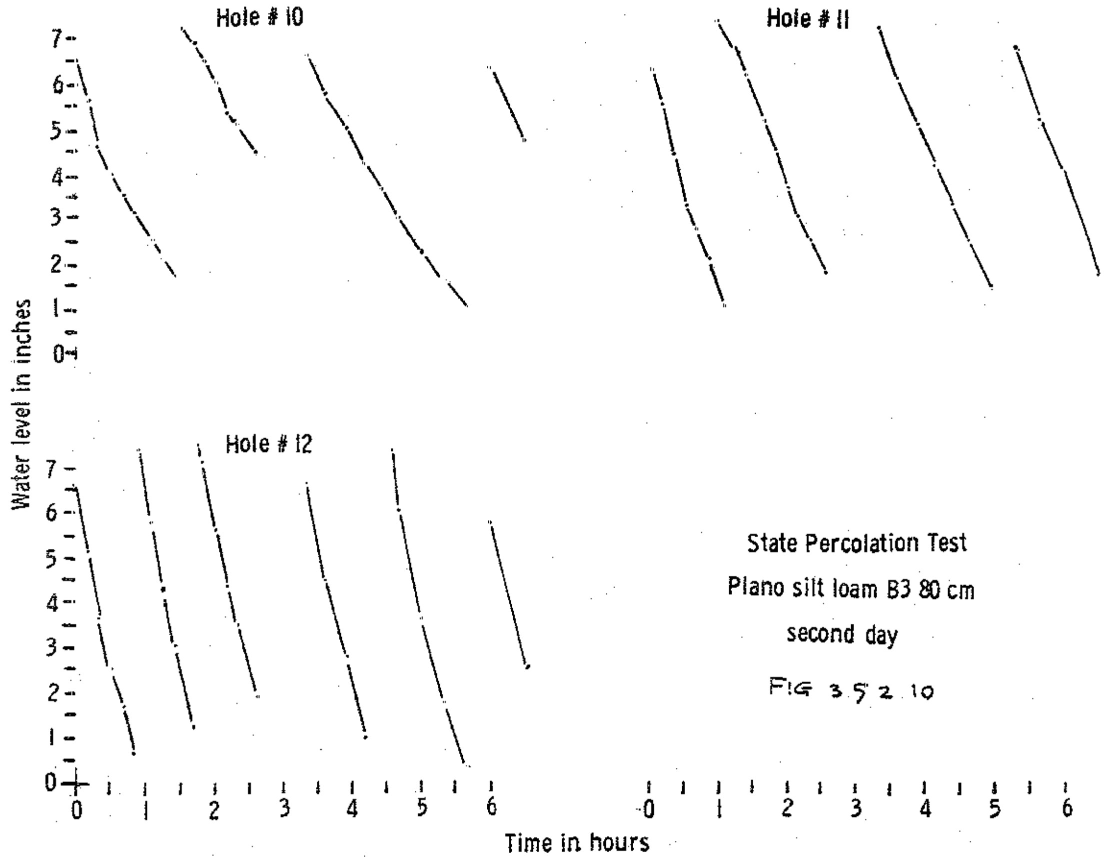
State Percolation Test
Plano silt loam B2 50 cm
second day

FIG 3.5.28



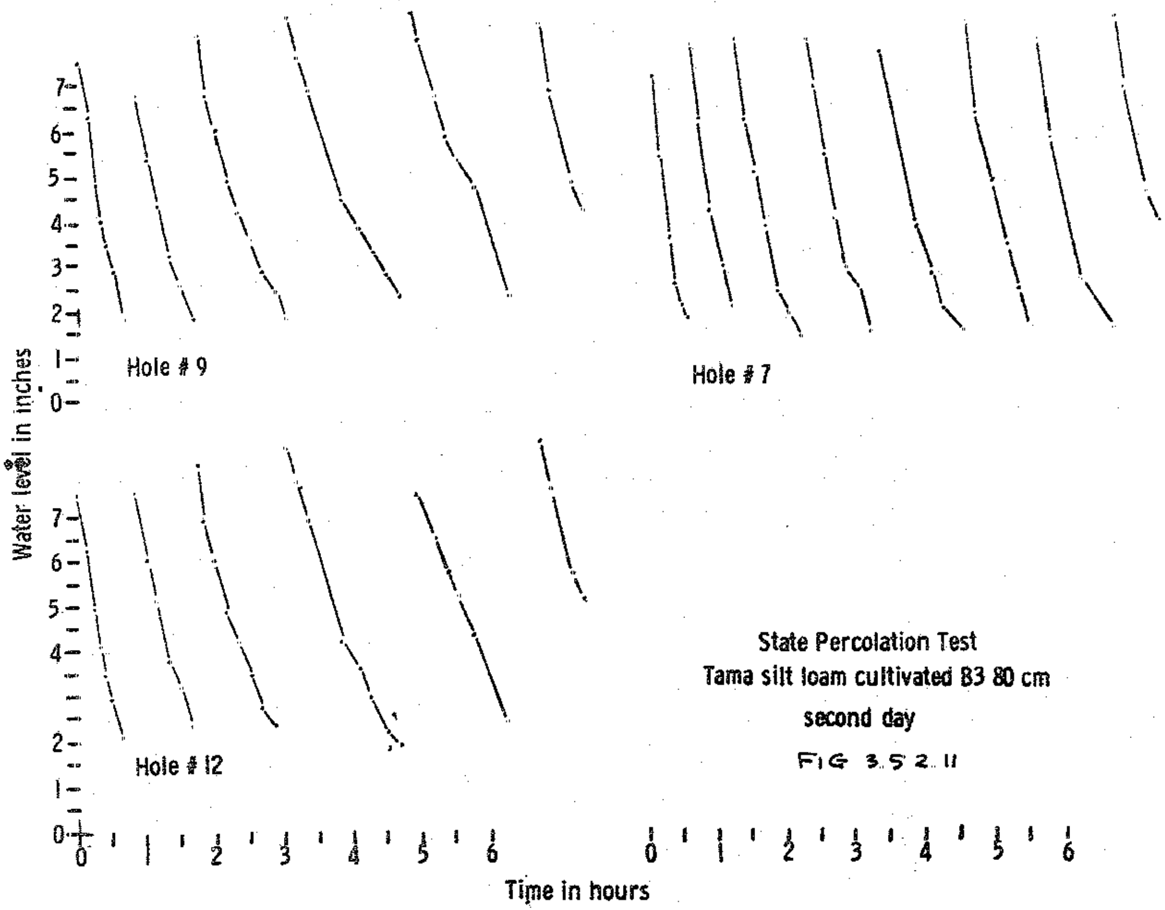
State Percolation Test
Plano silt loam B3 80 cm
first day

FIG. 3.5.2.9



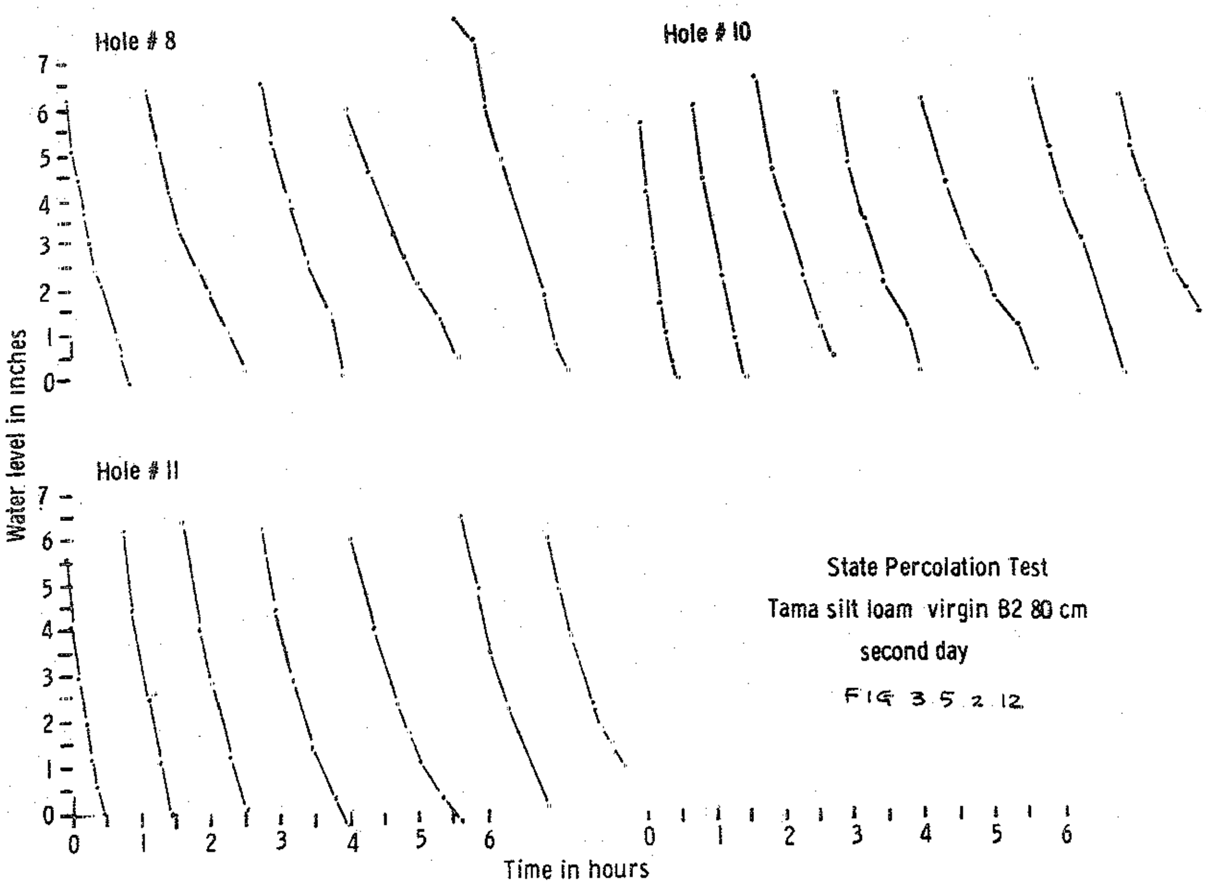
State Percolation Test
Plano silt loam B3 80 cm
second day

FIG 3.5.2.10



State Percolation Test
Tama silt loam cultivated B3 80 cm
second day

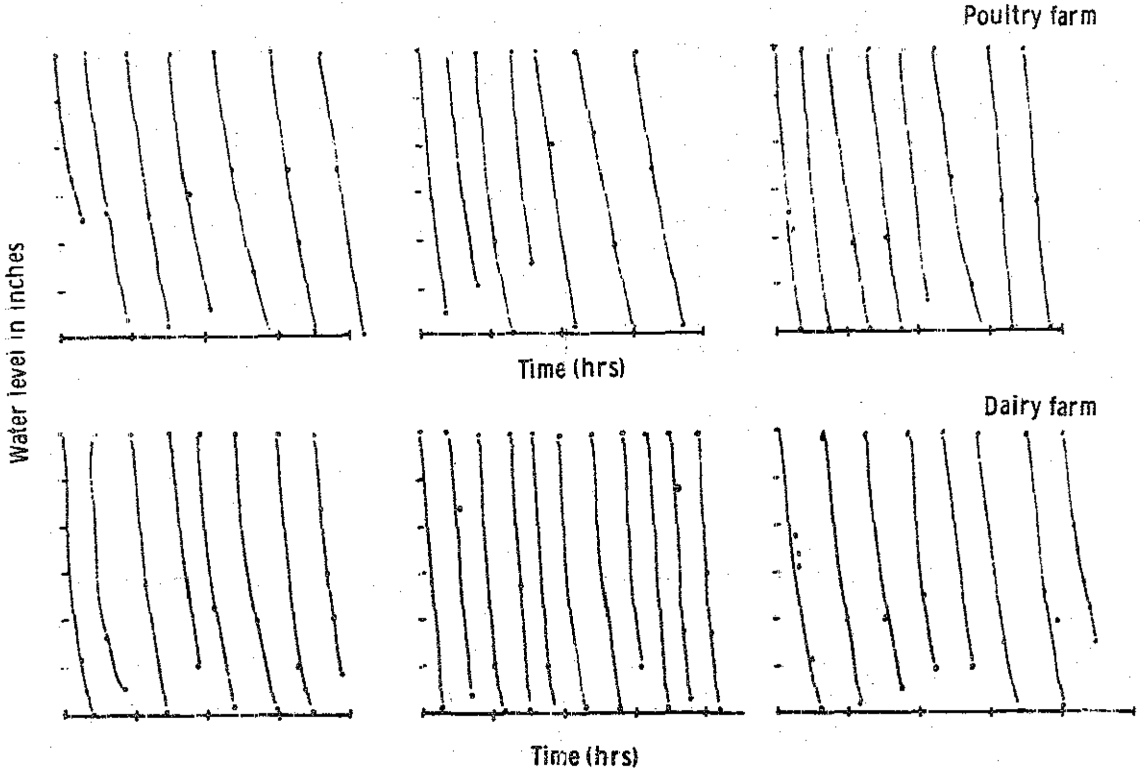
FIG 3.5.2.11



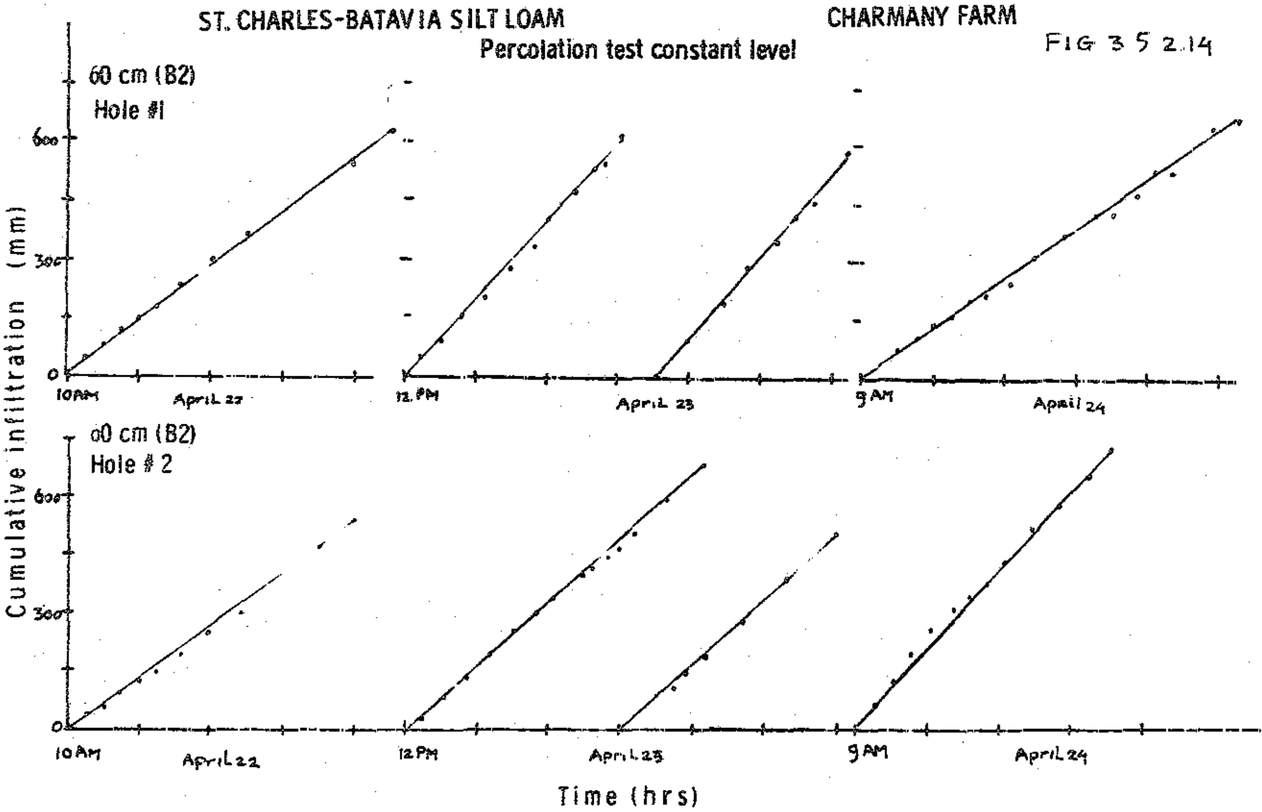
State Percolation Test
Tama silt loam virgin B2 80 cm
second day

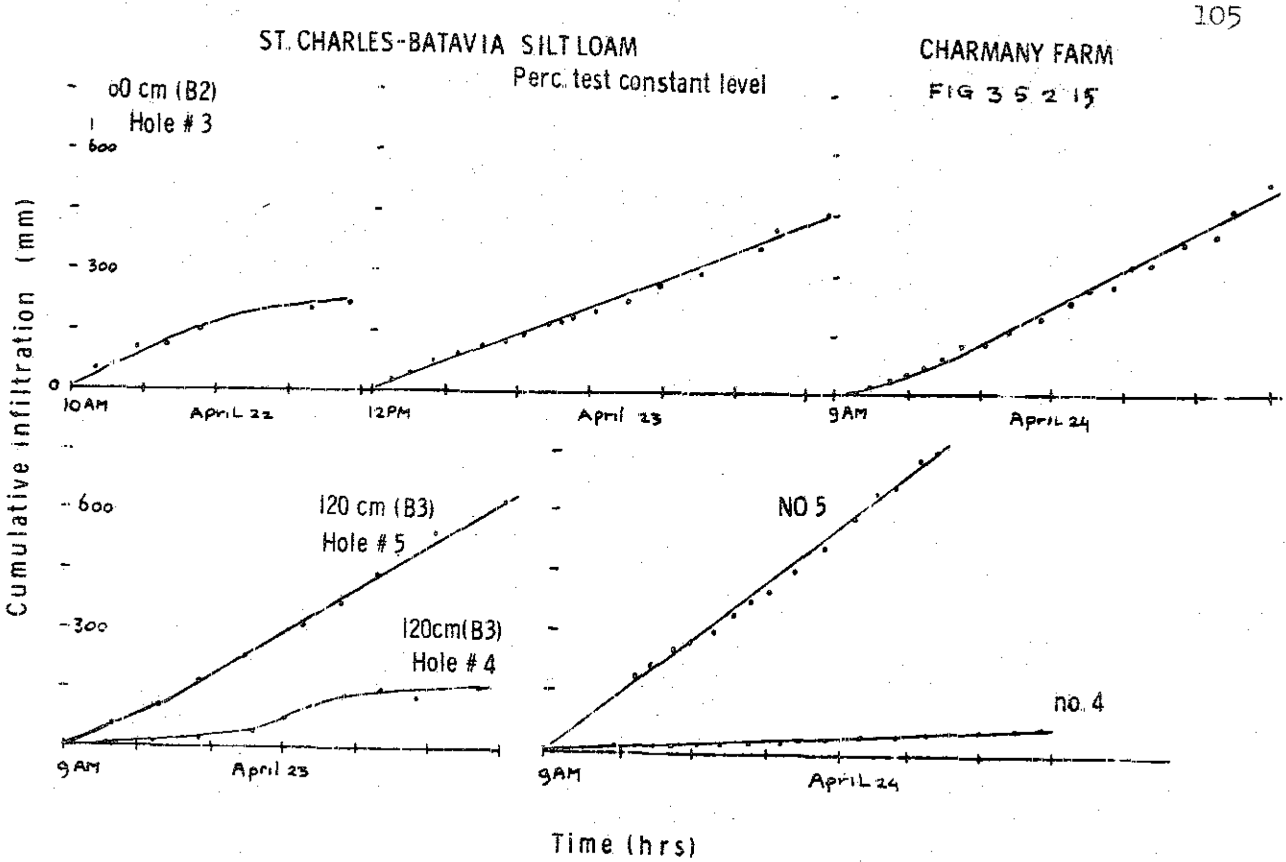
FIG 3.5.2.12

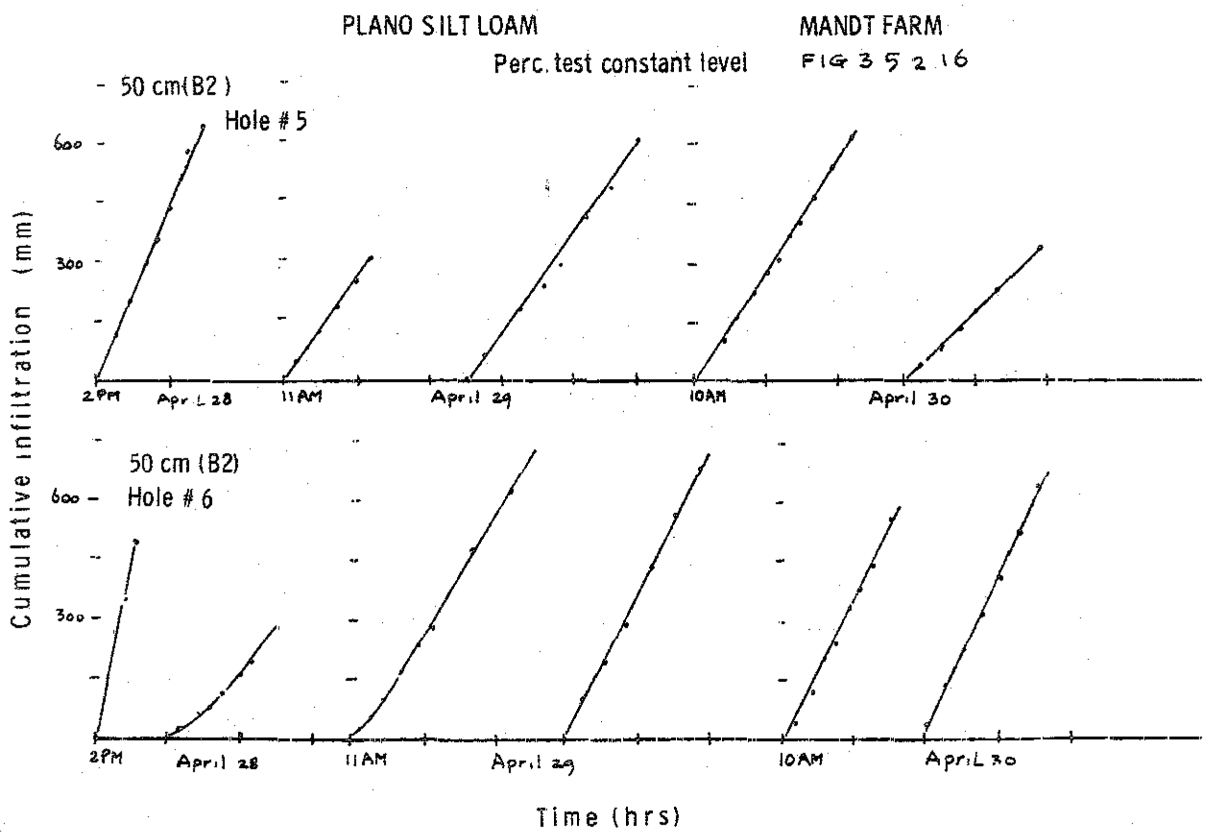
State percolation test in stony sandy loam till (Arlington exp. farm) SECOND DAY FIG 3 5 2 13

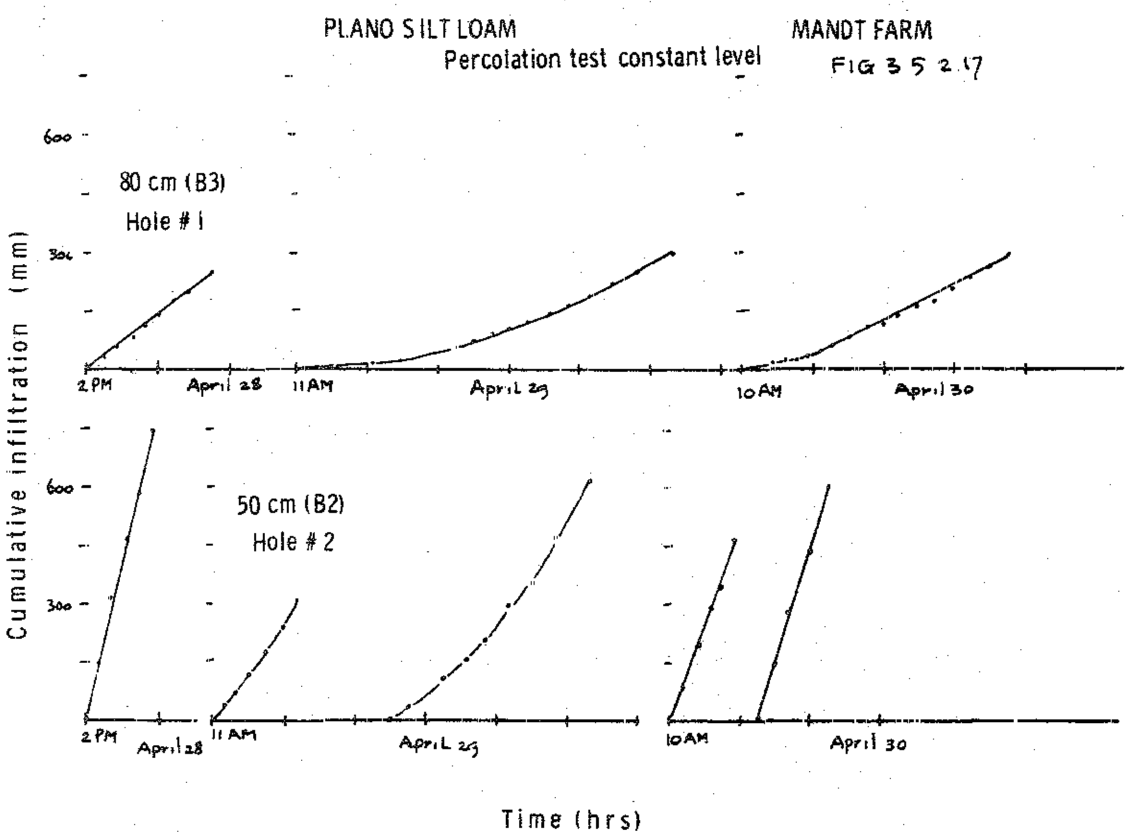


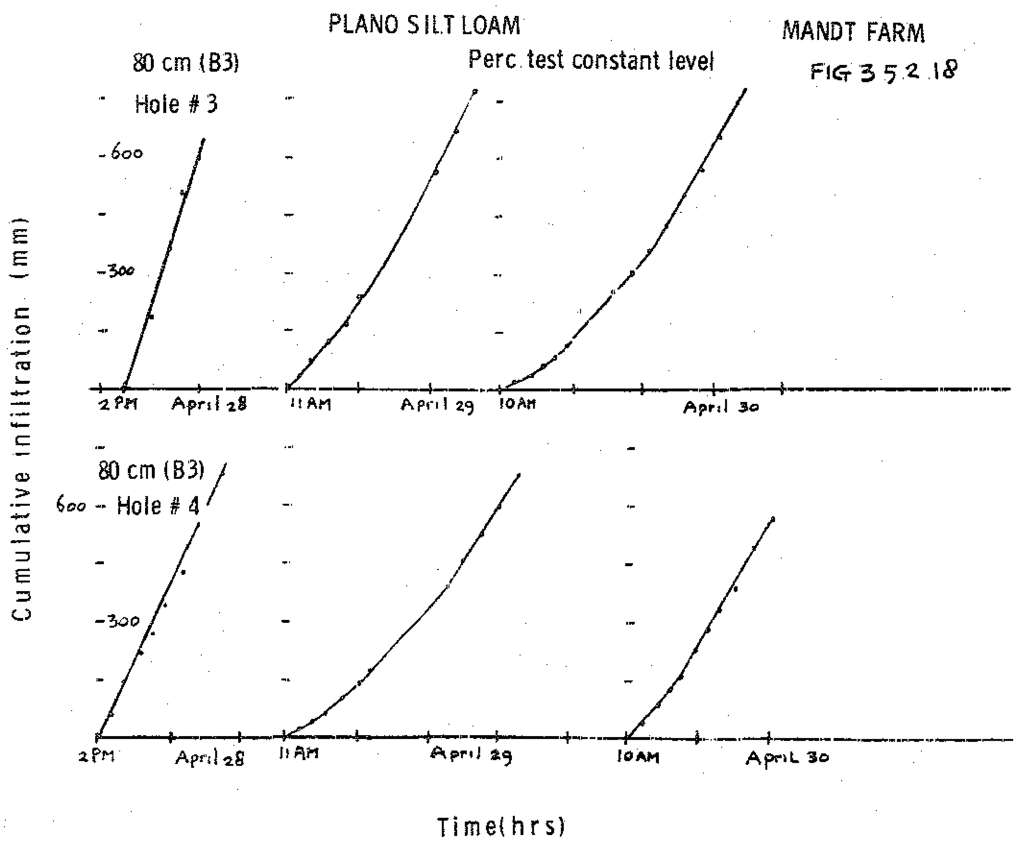
ST. CHARLES-BATAVIA SILT LOAM CHARMANY FARM
Percolation test constant level FIG 3 5 2.14



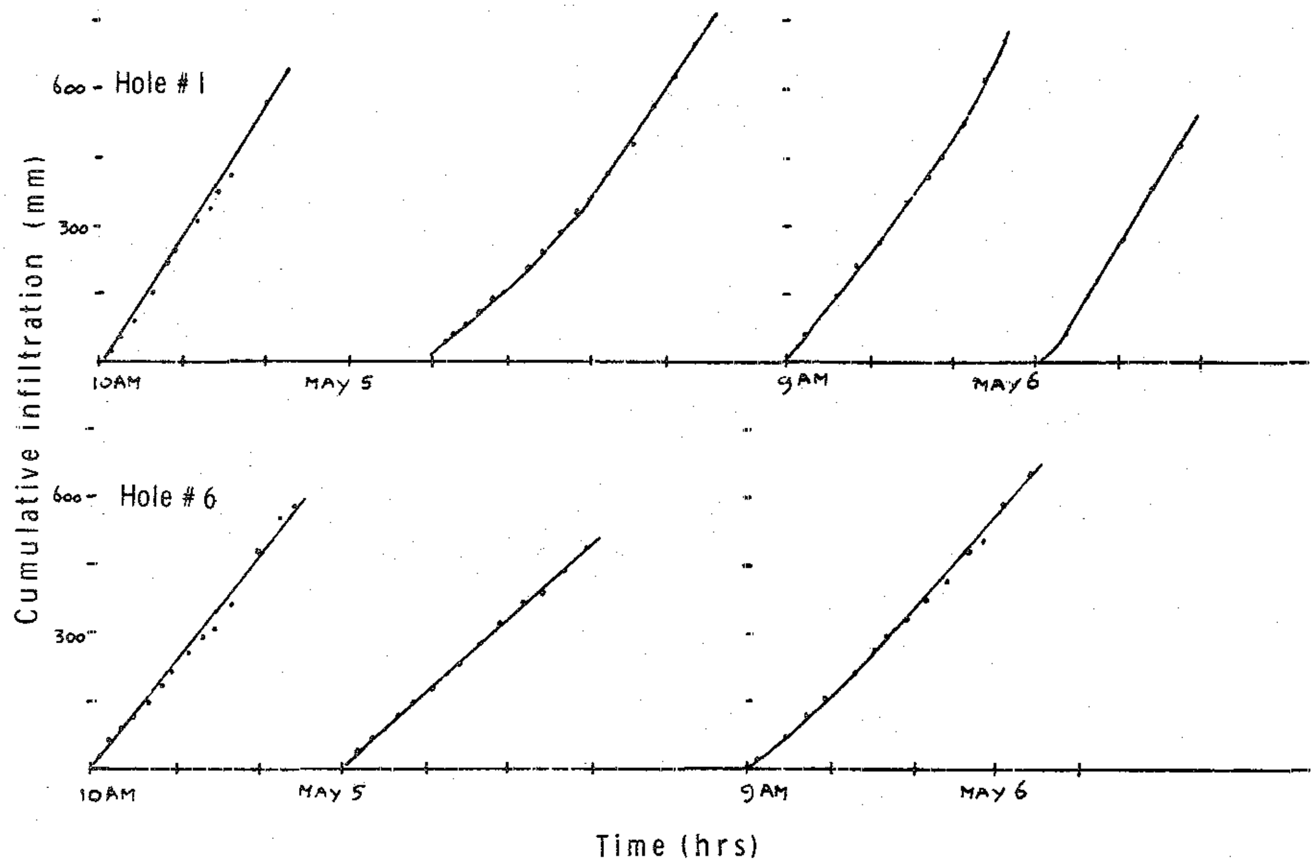

ST. CHARLES-BATAVIA SILT LOAM
Perc. test constant level
CHARMANY FARM
FIG 3 5 2 15
60 cm (B2)
Hole # 3
600
300
0
10AM
April 22
12PM
April 23
9AM
April 24
Cumulative infiltration (mm)
600
120 cm (B3)
Hole # 5
300
120cm(B3)
Hole # 4
9AM
April 23
NO 5
no. 4
9AM
April 24
Time (hrs)


PLANO SILT LOAM
MANDT FARM
Perc. test constant level
FIG 3 5 2 16
50 cm(B2)
Hole # 5
600
300
2PM
April 28
11AM
April 29
10AM
April 30
Cumulative infiltration (mm)
50 cm (B2)
Hole # 6
600
300
2PM
April 28
11AM
April 29
10AM
April 30
Time (hrs)

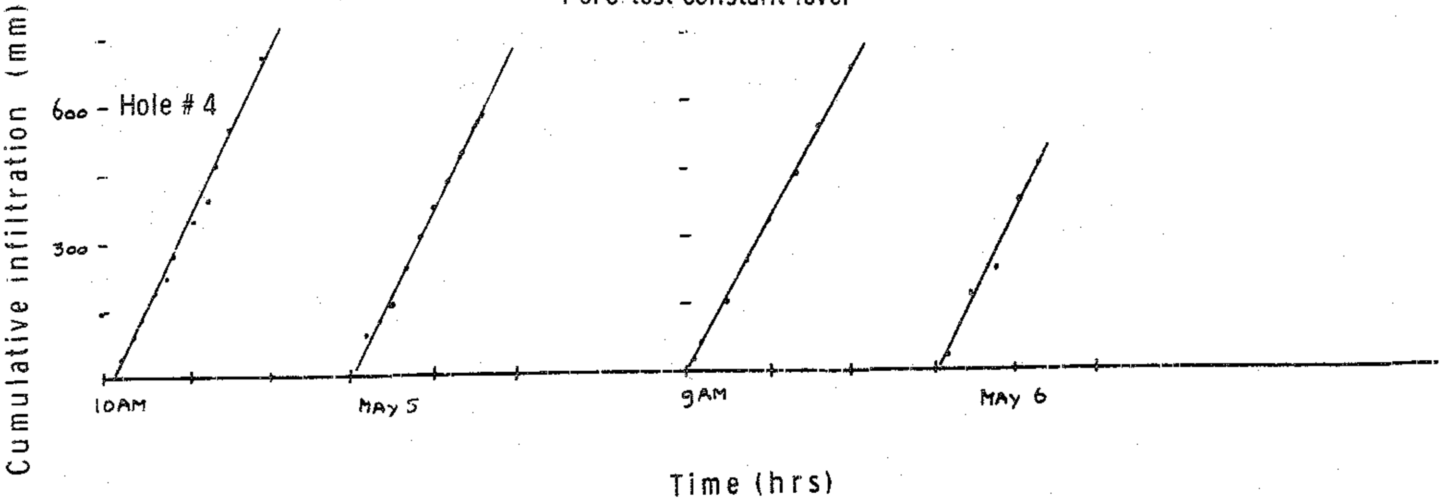

PLANO SILT LOAM
Percolation test constant level
MANDT FARM
FIG 3 5 2.17
80 cm (B3)
Hole # 1
50 cm (B2)
Hole # 2
Cumulative infiltration (mm)
600
300
2 PM
April 28
11 AM
April 29
10 AM
April 30
Time (hrs)


PLANO SILT LOAM
Perc. test constant level
MANDT FARM
FIG 3 5 2 .18
80 cm (B3)
Hole # 3
80 cm (B3)
Hole # 4
Cumulative infiltration (mm)
600
300
2 PM
April 28
11 AM
April 29
10 AM
April 30
Time(hrs)

TAMA SILT LOAM(VIRGIN PRAIRIE) AT 80 CM DEPTH (B21) PLATTEVILLE
Percolation test constant level FIG 3.5.2.19

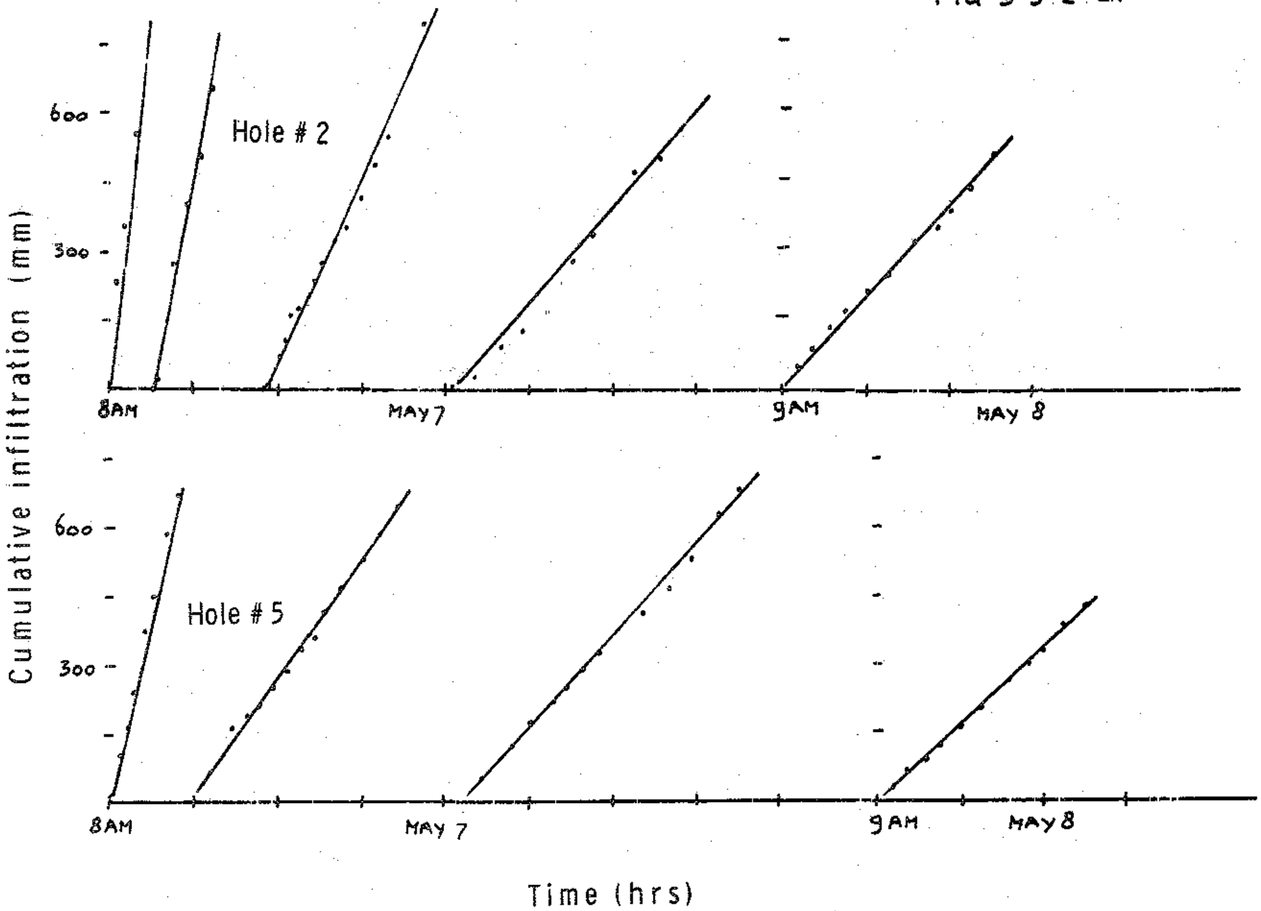


TAMA SILT LOAM (VIRGIN PRAIRIE) AT 80 cm DEPTH (B21) PLATTEVILLE
Perc. test constant level FIG 3.5.2.20



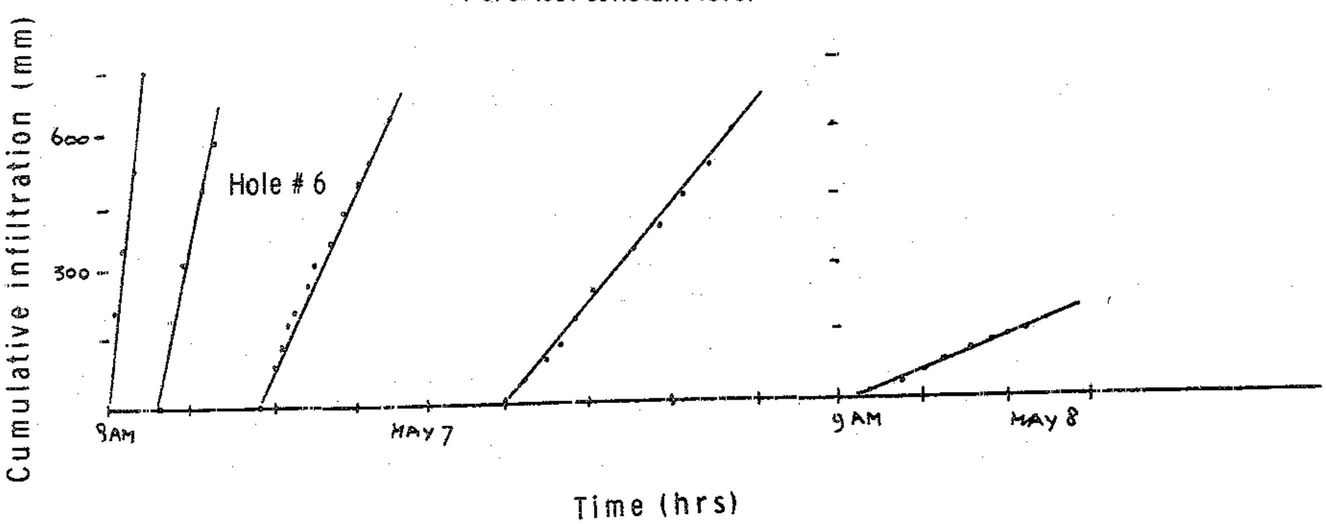
TAMA SILT LOAM (CULTIVATED) AT 80 cm DEPTH (B3I) PLATTEVILLE
Percolation test constant level

FIG 3 5 2 21



TAMA SILT LOAM (CULTIVATED) AT 80 cm DEPTH (B3I) PLATTEVILLE
Perc. test constant level

FIG 3 5 2 22



Stony sandy loam till (Arlington exp. farm)

Percolation test constant level

FIG 3.5.2.23

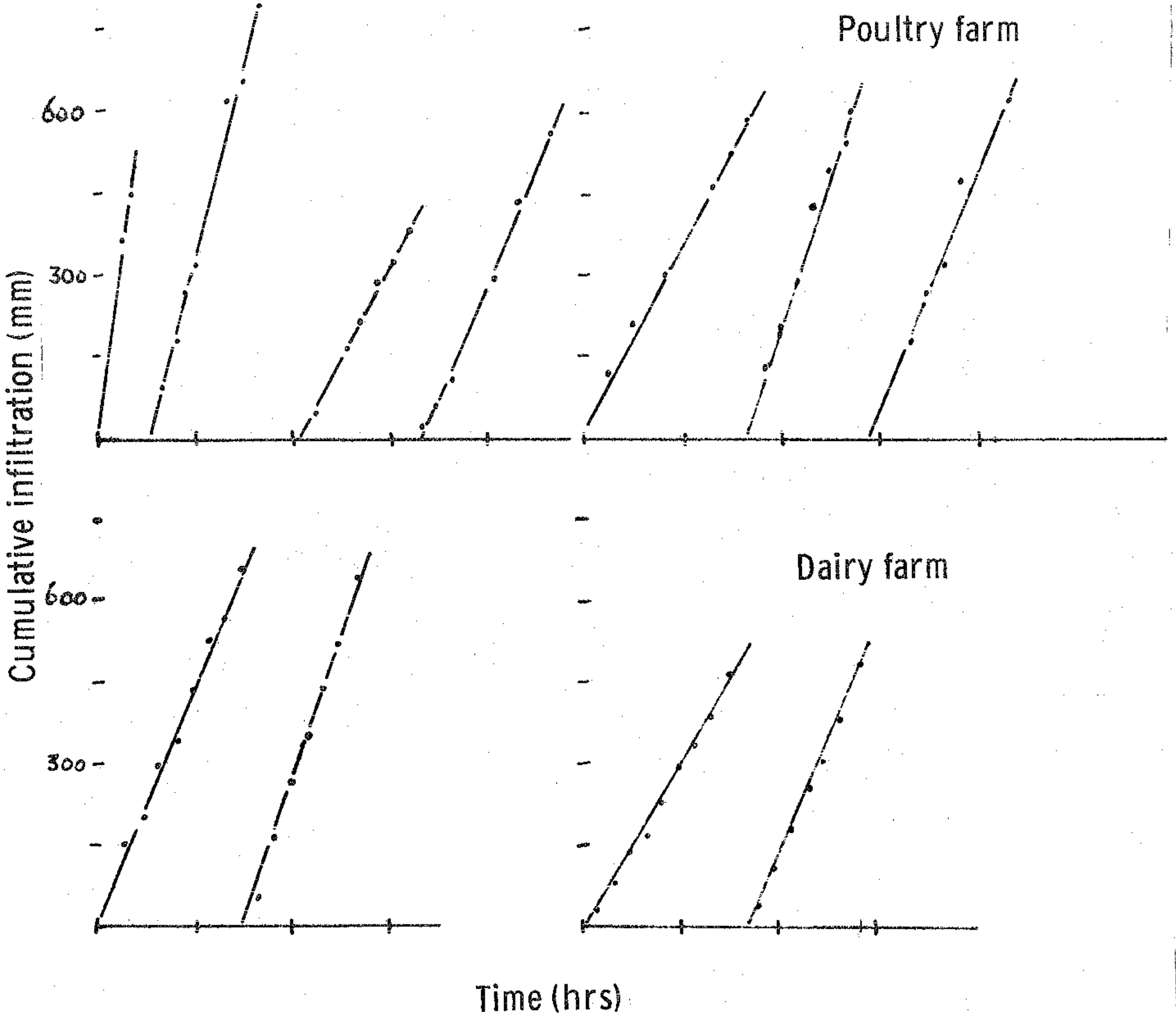


Photo 3.6.2 Mound System I.
The mound is indistinct because the upper end (E) is at the same level as the surface of the adjacent area. This picture was taken from point 1 in Fig. 3.6.2a. The bank of the lake (L) is at the corner of the picture.

Mound system for the disposal of septic tank effluent

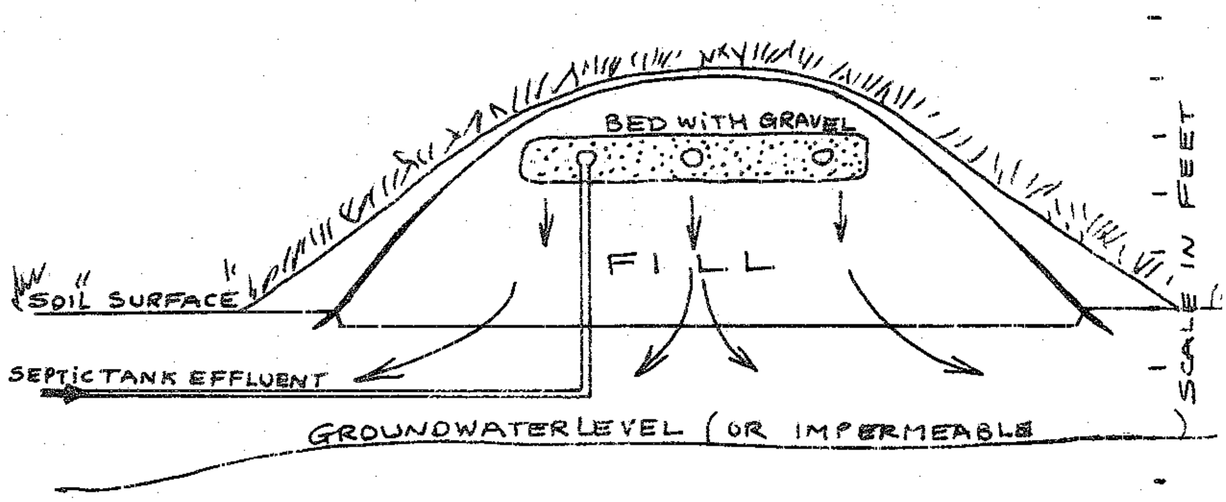


Fig. 3.6.1a

Conventional soil disposal system for septic tank effluent

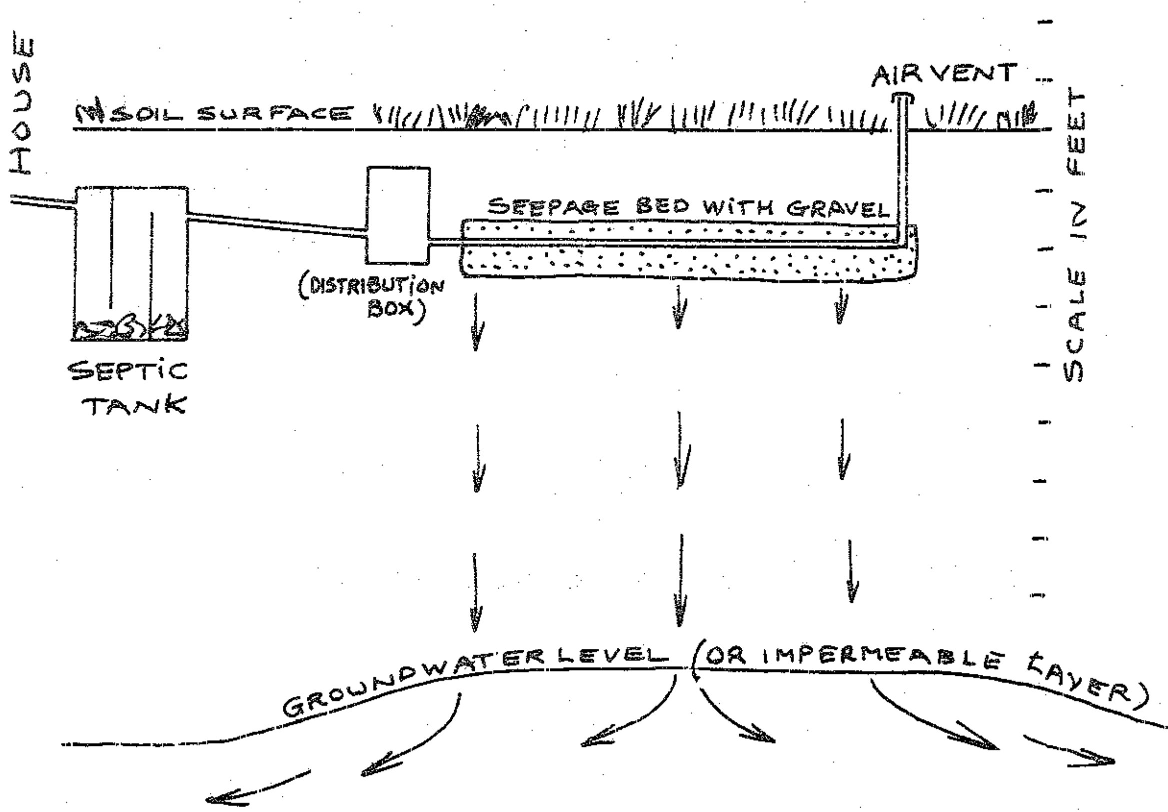


Fig. 3.6.1b

3.6. The experimental mound systems in Clark County, Wisconsin

3.6.1. Introduction

Obviously, liquid waste disposal through soil absorption can only be successful when the soil to be used is capable of absorbing a sufficient amount of liquid. Soils with a percolation rate of more than 60 minutes per inch are classified as unsuitable for on-site liquid waste disposal, as are sites with groundwater or bedrock within 3 feet of the surface, or with steep slopes (State Board of Health, Chapter H22 (1969). These prohibitive conditions apply to an estimated 55% of the land area of Wisconsin. Strictly following the letter of the law, on-site liquid waste disposal is not possible in more than half of the State. Two alternatives, a public treatment plant and holding tanks, seem to be unacceptable. Public sewer systems cannot be constructed economically in sparsely populated rural or suburban areas. The cost of construction and servicing of a large holding tank is prohibitive. The result is that many people, sometimes encouraged by "specialists" promising the impossible, try to build a system anyway. It usually does not work and the result is that raw sewage flows into road ditches and stagnent pools, creating a health hazard.

In this chapter the results will be reported of a preliminary study of experimental mound systems (or NODAK systems), constructed in Clark County, Wisconsin with special permission of State Board of Health officials, to study possibilities for on-site effluent disposal in soils with high groundwater, low permeability or other limitation.

The effluent flows by gravity or is pumped into a mound of soil about 4 feet high and resting on the original soil surface. The liquid percolates downwards through the unsaturated soil material in the mound into the underlying soil profile (see Fig. 3.6.1a).

The bottom of a seepage trench in a traditional system (Fig. 3.6.1b) in a permeable or well drained soil is usually placed at a depth of about 3 feet. The liquid moves down and laterally from that level. A mound system differs primarily in being elevated about 5 feet, as compared to the traditional system. The effect is to increase the thickness of soil available for percolation before the treated effluent reaches the groundwater or a perched water table on top of an impermeable layer.

Some potential advantages of a mound system are: 1) The size and shape of the mound, and the textural composition of the fill material can be more easily controlled than can the subsoil in a regular system, to create conditions for optimal treatment and, when necessary, for temporary storage of effluent. 2) The upper soil horizons are usually more permeable than the underlying B horizon, so that lateral movement of liquid after downward percolation through the mound may occur relatively easily, despite the unsuitability of the subsoil. 3) Because the mound is surrounded by air above and on all sides, the interior may be better aerated than the soil surrounding a conventional buried system. As a result aerobic decomposition of effluent compounds may be better in the mound system. Care must be taken that the surface layers of the mound do not restrict air diffusion unduly.

Some potential problems are: 1) Stoppage of movement of liquid in the system by freezing in the tile lines, in superficial soil layers of the mound, and in the original surface soil around the mound. The unfrozen core of the mound might, under resulting anaerobic conditions, still act as a storage tank but would not effectively treat the effluent. The same effect would result whenever the loading rate exceeded the capacity of the soil to conduct the moisture away from the system. 2) Seepage of polluted effluent from the sides of mounds of moderate size onto the surrounding soil surface may take place

SOIL ABSORPTION SYSTEM : MOUND SYSTEM I (Neillsville, wis)

Humbird sandy loam

Top view mound

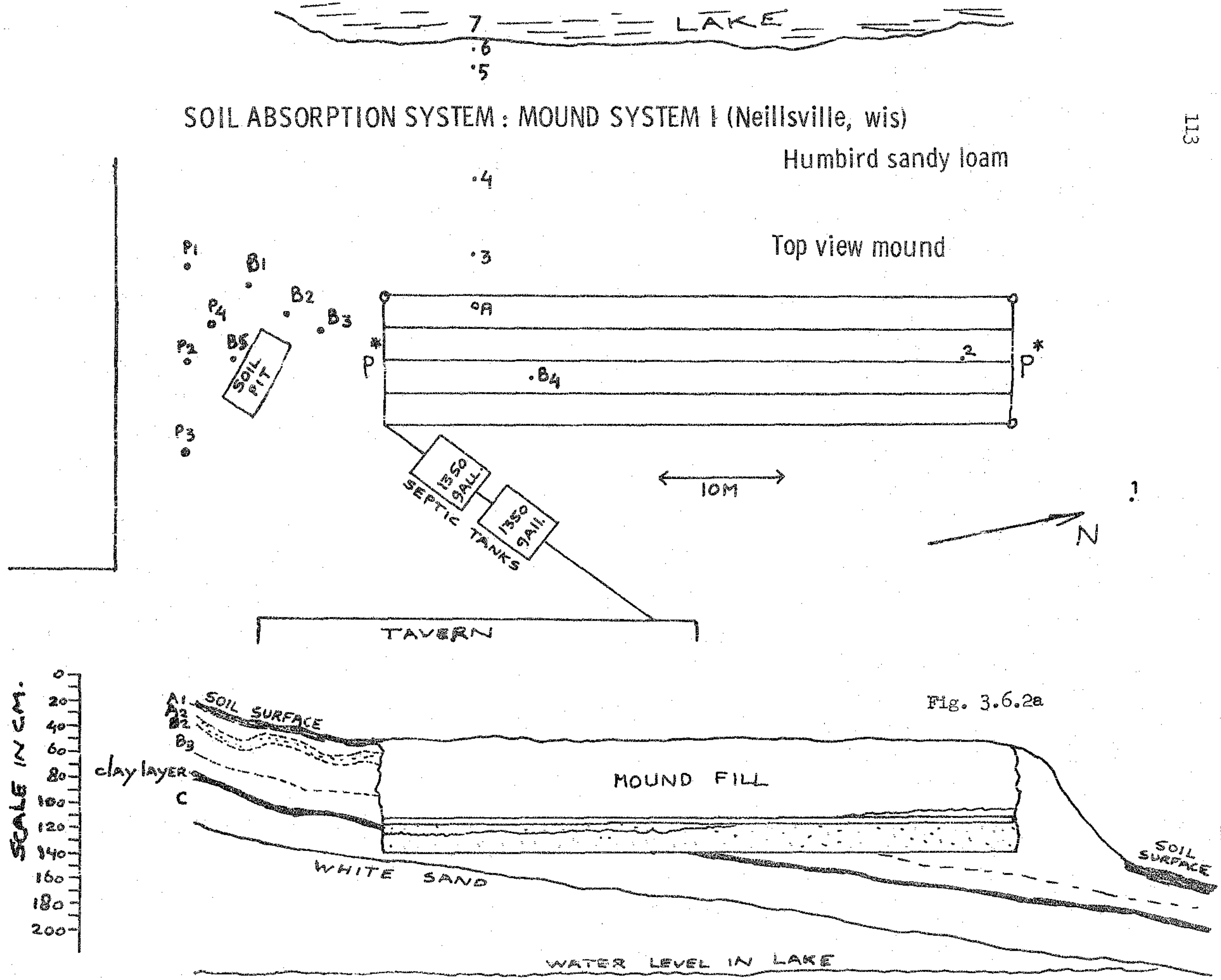


Fig. 3.6.2a

Section of mound (pp)*

in times of excessive rain or snow melt or in case of overloading of the system from within.

Construction of a mound system is one way to attack the problem of liquid waste disposal on sites where soil conditions prevent a conventional system from working. Spraying of effluent over agricultural land or aeration and/or chlorination of effluent are alternatives, and can possibly be combined with other schemes. Because this study has centered on soil conditions and related hydraulic phenomena, attention will be focused on the mound system as a possible alternative to the conventional one. The following report is preliminary and is to be followed by others as monitoring of selected mound systems progresses.

3.6.2. Mound System I, on Humbird sandy loam (over sandstone with impervious shale layers)

3.6.2.1. Introduction

This system was investigated in June, 1970. Samples of soil and liquid for bacteriological and fertility studies were taken on July 30, 1970. The Humbird sandy loam (see profile description) developed in a sandy cover over stratified weathered shaly sandstone.

A top view of the mound system and a section along the line Mo-Mo, are in Fig. 3.6.2a (see also Photo 3.6.2). The locations of the Bouwer tests (B) and State Percolation Tests (P) are indicated. Seven samples (numbered 1-7) (Figures 3.6.2a and b) were taken for chemical and bacteriological analyses (July, 1970). The experimental mound system was constructed here, because of seasonal high perched groundwater that would have prevented proper functioning of a conventional system. The system was built in the early fall of 1969. Grading of the original sloping soil surface (Fig. 3.6.2a) intersected through

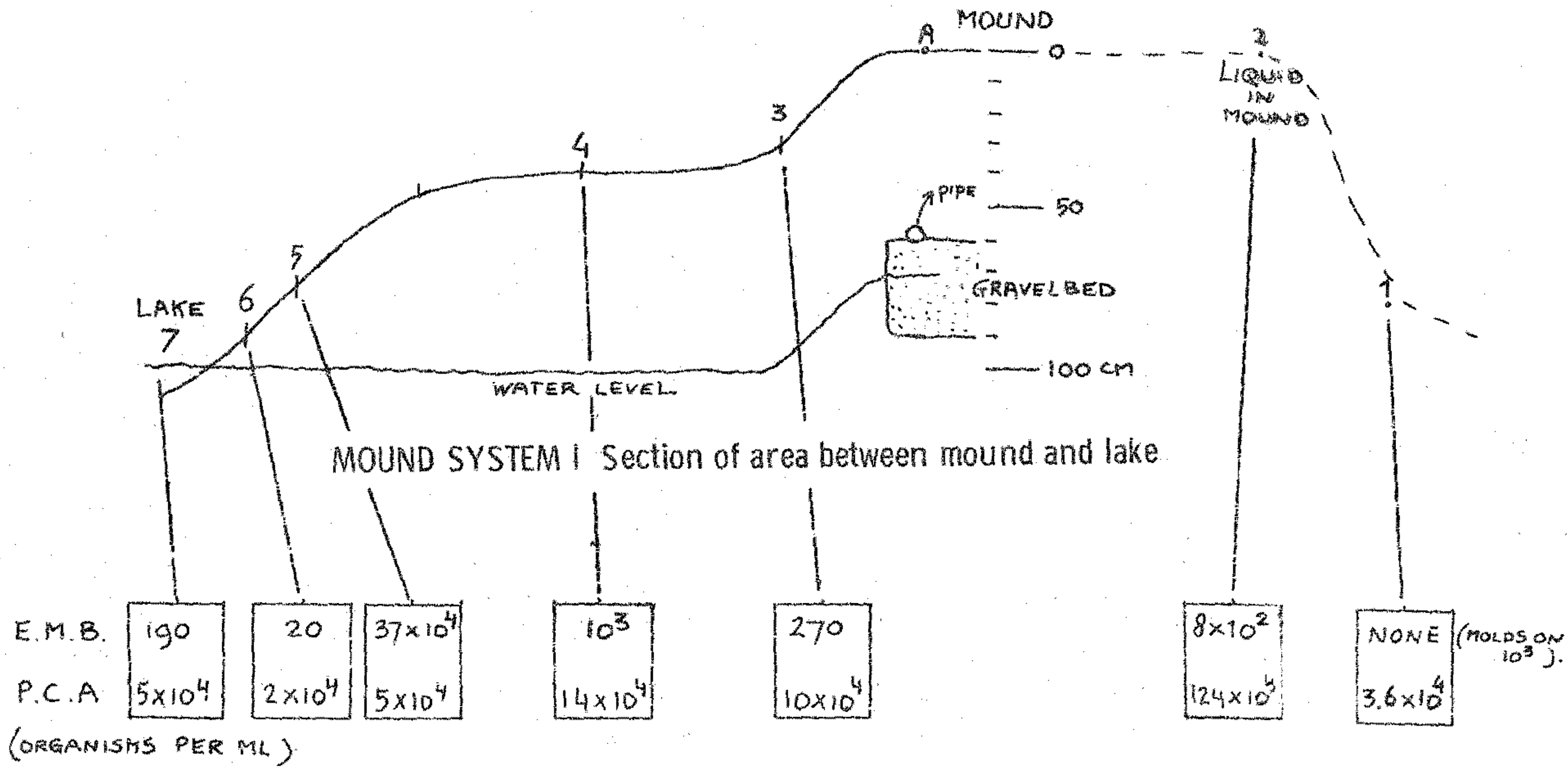


Fig. 3.6.2b Results of bacteriological analyses of liquid in the mound and groundwater

some impermeable soil horizons upslope. Half a year later a small recreational lake was constructed at a distance of about 100 feet from the mound system.

3.6.2.2. Results

At the time of investigation, the system seemed to be absorbing all effluent delivered to it, despite very high loading rates (estimated to be 1000 gallons/day.) Hydraulic conductivity values are presented in Table 3.6.2a. and show a striking change from sandy loam solum to underlying clay and sand.

Table 3.6.2a. Hydraulic conductivity of Humbird sandy loam.

Horizon	Hydraulic conductivity (K) measured with Bouwer double tube apparatus	State Percolation Test, conventional	Perc. Test Constant Level
B2	20 cm/day	---	---
B3	12 cm/day	---	---
IIC green shale band	3 cm/day	---	---
IIIC white soft sand-stone sand	500 cm/day	900 cm/day 4 min/inch	864 cm/day 4 min/inch
Fill in the mound	50 cm/day	---	---

Table 3.6.2b. Nutrient content of water from seven sampling holes in and near Mound System I.

Sample No. and location	Total P	Inorganic P ppm	Organic P ppm	NO_3 ppm	NH_4 ppm
1	7.5	.1	7.40	1.1	0
2	9.2	.5	8.70	1.9	0
3	8.0	.4	7.60	1.5	2.0
4	10.0	.15	9.85	0.6	1.2
5	7.4	.25	7.15	4.2	0
6	10.0	.2	9.80	4.8	1.2
7	9.8	.2	9.60	2.0	1.2

State Percolation test Mound system I 85 cm

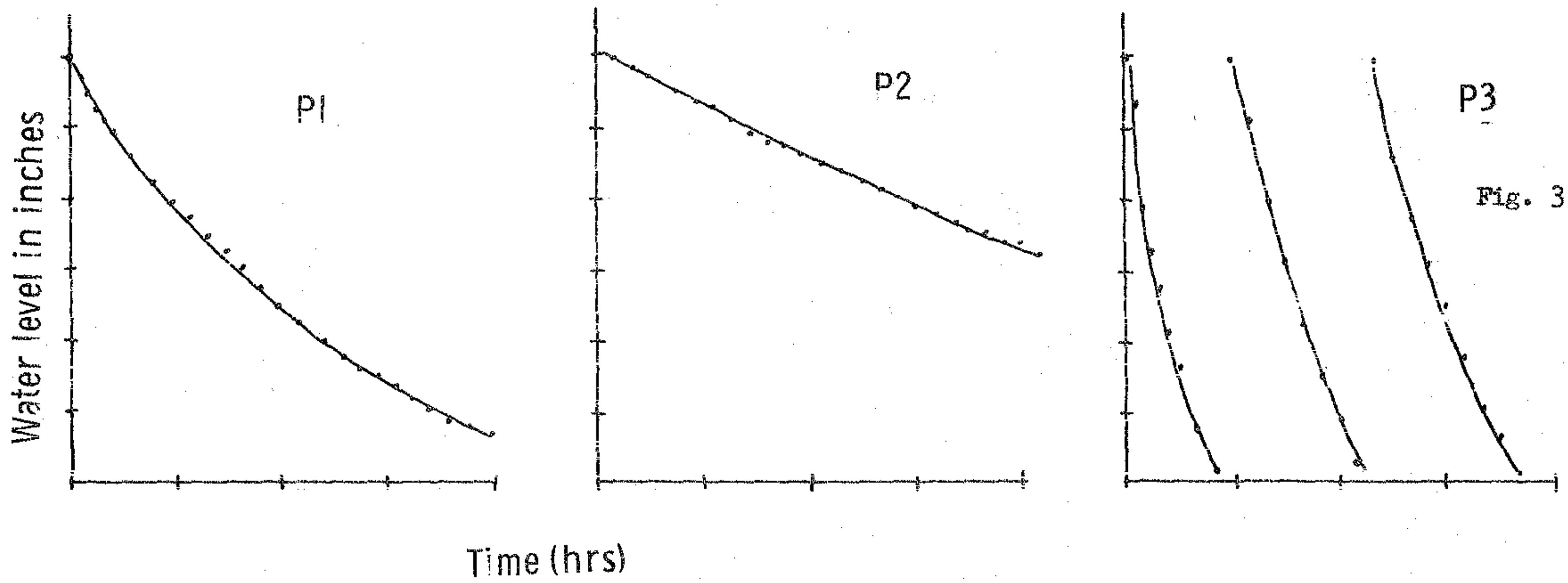


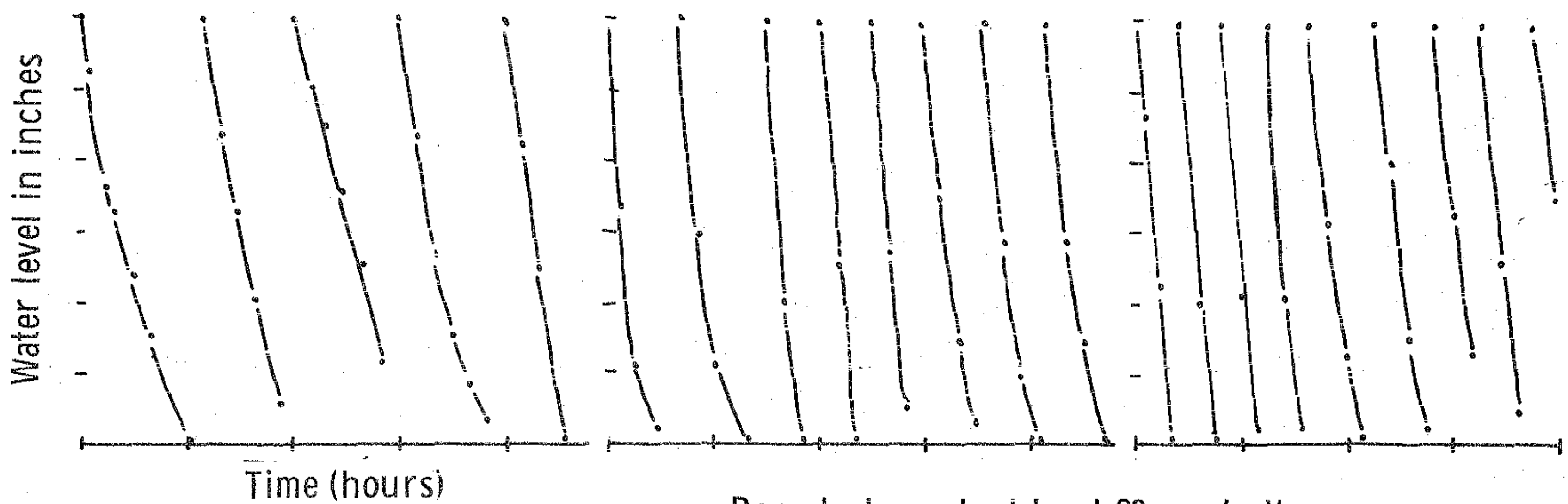
Fig. 3.6.2c

PERCOLATION TEST RESULTS IN WHITE SAND

IIIC horizon

State perc. test at 80 cm depth Mound system II

on Humbird sandy loam



Perc. test constant level 80 cm depth

Mound system I

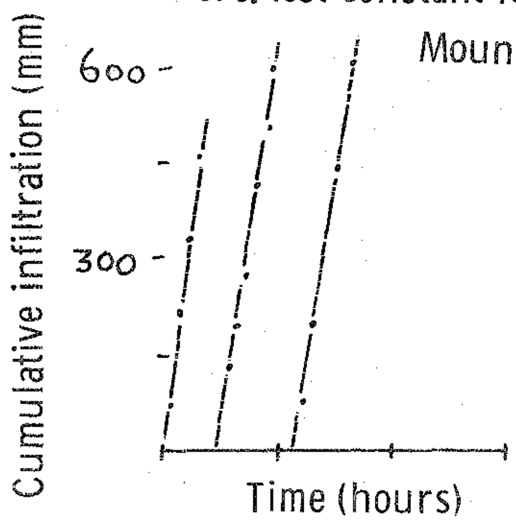
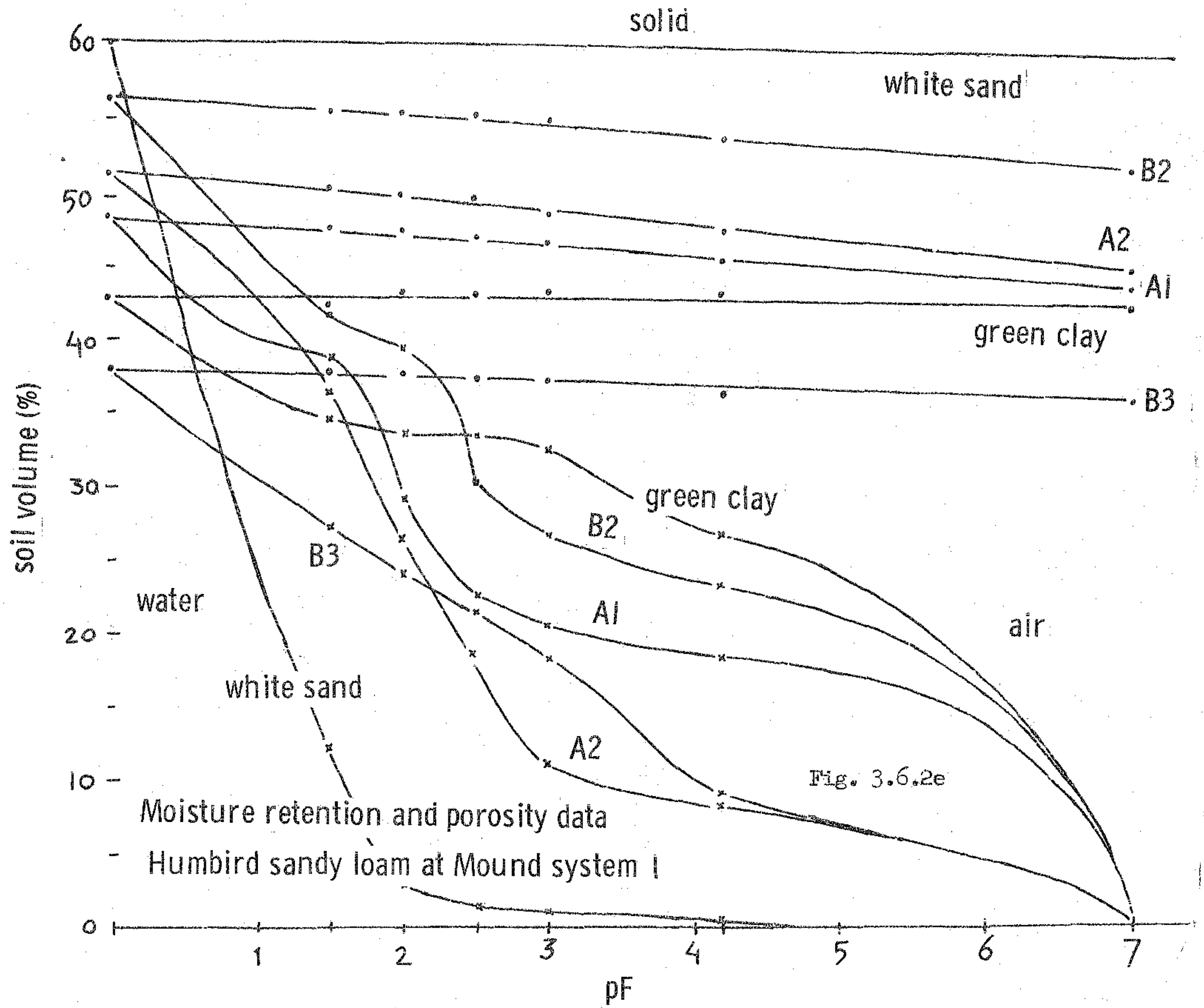


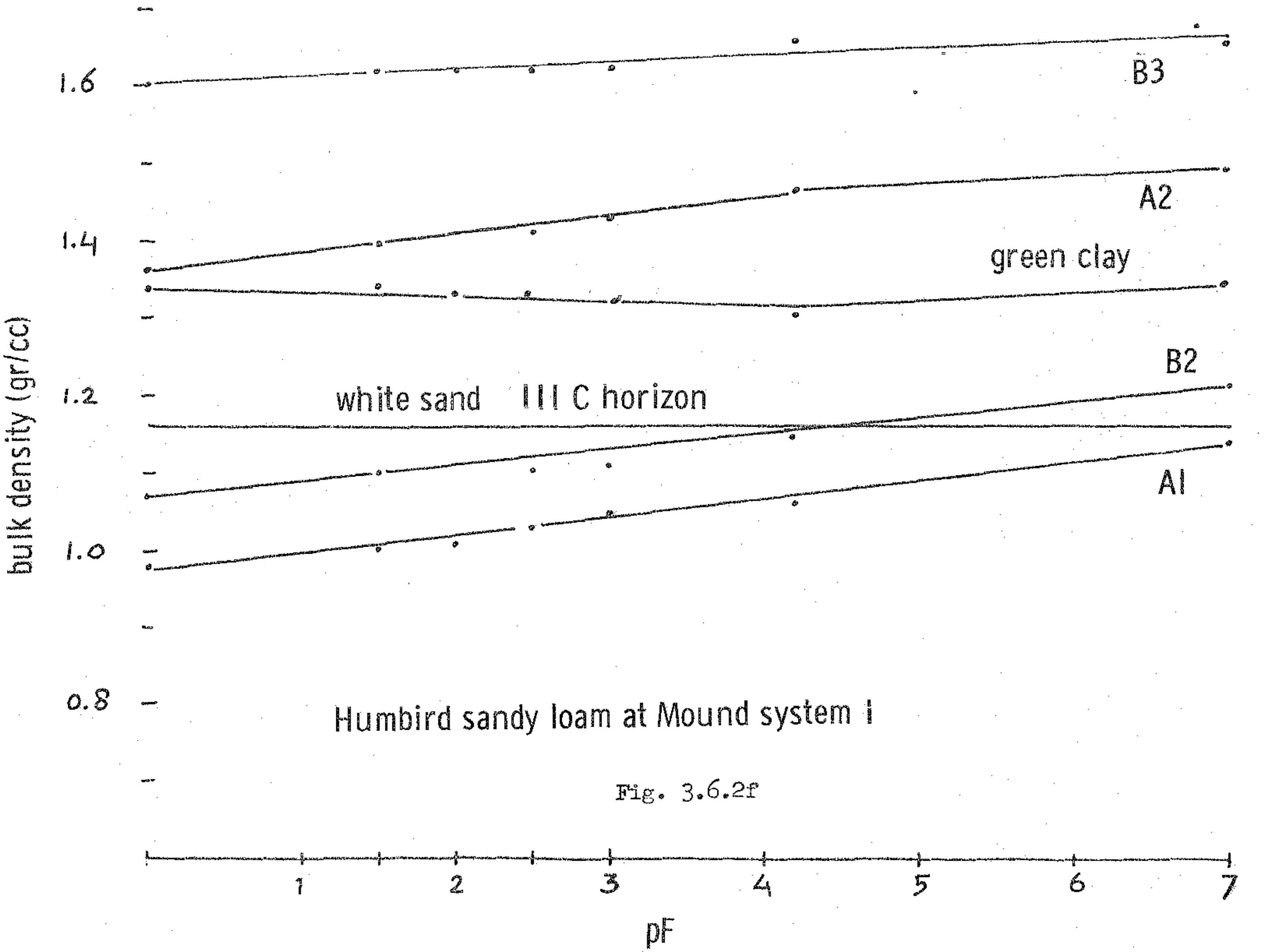
Fig. 3.6.2d

Results of the State Percolation Test at a depth of 85 cm showed highly variable results (Fig. 3.6.2c) due to the presence of the clay layer at varying depth. A constant level percolation test in the white sand (Fig. 3.6.2d), yielded a high percolation rate (Table 3.6.2a). Moisture retention, porosity and bulk density data of the pedon are presented in Figures 3.6.2e and f. Microbiological data are plotted in a section of the area (Fig. 3.6.2b) to show the effect of distance of percolation on the biological properties of the liquid. Analyses of nutrients in samples from the same sources are reported in Table 3.6.2b.

3.6.2.3. Discussion

The investigated system differs from the prototype (Fig. 3.6.1a) in that 1) effluent is not fed into the upper part of a mound, and 2) the mound is not built on top of the soil surface, but on a surface of excavation, and 3) the surface of one end of the "mound" is not elevated at all but is actually in a footslope position (Fig. 3.6.2a). The soil material covering the tile lines and gravel bed in the mound is composed of a very heterogeneous mixture of material from all soil horizons. The average bulk density of the soil fill is 1.7, and the estimated porosity 41 percent. The upper fill portion of the mound is not used for percolation of effluent, but serves to shed some precipitation, to confine the gravel seepage bed and prevent surfacing of fresh effluent. The IIIC horizon of the original soil is very permeable, and directly underlies the upslope half of the system. Due to the absence of an organic crust in this young system the effluent can be expected to move rapidly through the sand. Pollution of the recreational lake, only 30 meters away, is indicated by the data in Table 3.6.2b. Contents of some nutrients tend to increase with proximity to the lake, as in the case of trends of P and NO_3 from sampling point 2 to points 5 and 6, where the liquid is about to flow into the lake.


solid
white sand
B2
A2
Al
green clay
B3
green clay
B2
B3
Al
air
water
white sand
A2
Fig. 3.6.2e
Moisture retention and porosity data
Humbird sandy loam at Mound system I
soil volume (%)
60
50
40
30
20
10
0
1
2
3
4
5
6
7
pF



Humbird sandy loam at Mound system I

Fig. 3.6.2f

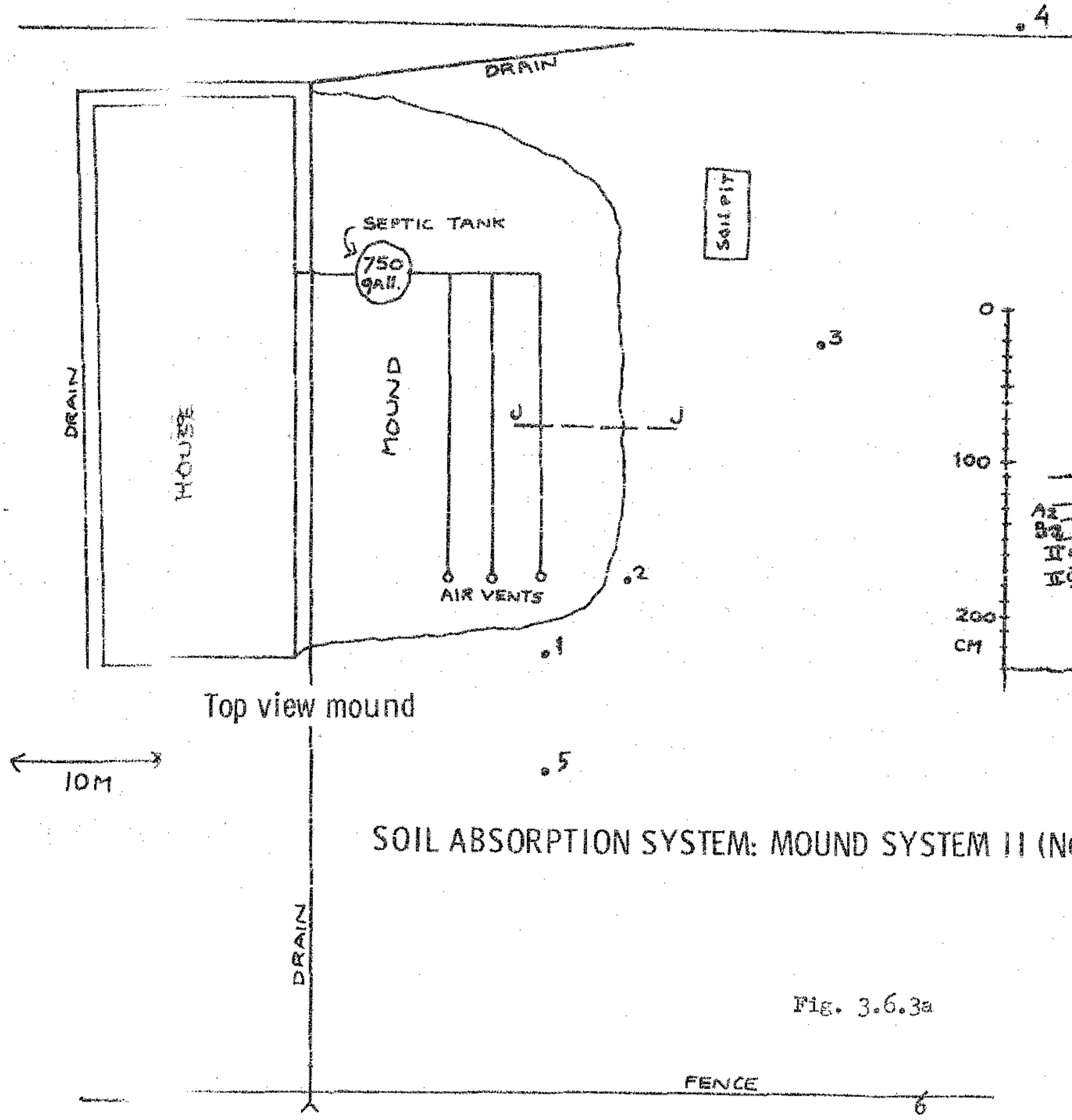
Total coliform counts (i.e. total growing on EMB plates) in the groundwater and in a lake water sample were high (10^2-10^4/mL) as compared to drinking water standards of 1 coliform organism/ml*. This cannot be taken as a direct indication that the coliform organisms in the lake originated from the near-by septic tank-mound system effluent for two seasons: 1) it was shown in all our samples that the "total coliforms" greatly exceeds the sheen-forming E. coli i.e. although the coliform total counts on EMB agar remained about 10^4-10^5/~~[illegible]~~ mL, indicating either organisms of soil origon or survival of non-E.Coli coliforms. Also note that non-fecal coliform types e.g. A. aerogenes sp. though found to comprise about one-half of the number of coliform organisms in fresh human feces may also be found as part of the natural soil microflora.

The vertical permeability of the mound system in the downslope half of the system is relatively low due to the presence of the clay layers just below the seepage bed (see Fig. 3.6.2a). Lateral seepage over these layers is to be expected. However, water samples taken at point 1 downslope and southeast of the system, did not indicate the occurrence of more serious pollution than at the points 3 to 6. The system may give problems in the future if clogging of the white sand develops and interferes with downward movement of effluent. The soil may become incapable of handling all the liquid introduced into the tile lines. Future monitoring of the system will indicate rate of change in this regard. During the winter season of 1970-1971 temperatures will be measured in the mound and surrounding soil to assess freezing hazard.

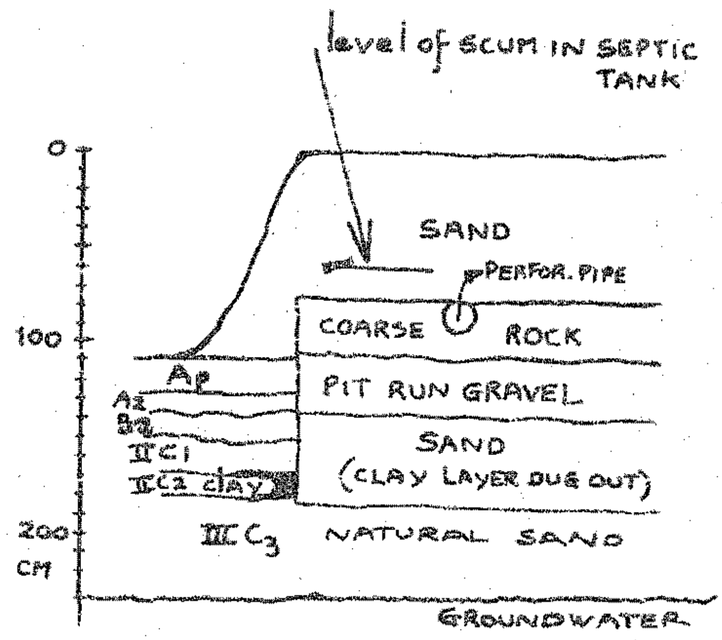
---

*PHS Drinking Water Standards, 1962.

Photo 3.6.3 Mound System II. (unfinished).
Effluent seeped through the side of the mound at point S in early June. Air vents (A) are at the ends of the three tile lines (see diagram of system, Figure 3.6.3a).



Top view mound



Section of mound (jj)

SOIL ABSORPTION SYSTEM: MOUND SYSTEM II (Neillsville, wis)

Fig. 3.6.3a

3.6.3. Mound System II, on Humbird sandy loam (over sandstone with impervious shale layers)

3.6.3.1. Introduction

Construction of this system (Fig. 3.6.3a) was begun in the Spring of 1970. The sand mound was still incomplete, was barren of vegetation, (Photo 3.6.3) and exhibited seepage from the sides in June, 1970. The soil type, a Humbird sandy loam, was similar to the soil at the site of Mound System I. Analytical data for this Humbird pedon, given in Chapter 3.6.2., applies therefore to this site. Construction of the mound was started by removing all clayey layers to a depth of about 3 feet and exposing the highly permeable white sand. The hole was filled with a layer of sand, pit run gravel and coarse rock (Fig. 3.6.3a). Perforated pipes were laid on a bed of coarse rock from the septic tank into the mound at a level slightly higher than the original soil surface. The whole system was covered with about two feet of coarse loamy sand. This material has a low porosity, (Fig. 3.6.3c) probably as a result of a wide range in particle size. The groundwater was observed to fluctuate considerably. In early June the level was at 50 cm below the soil surface ($\pm$ 70 cm below the pipe); in late July the level was 150 cm below the surface (Fig. 3.6.3b). The loading rate of the system was estimated to be 450 gallons/day. Samples for microbiological and chemical analyses were taken at the locations 1 through 6, in the septic tank and in a water well near the house on July 30, 1970.

3.6.3.2. Results and discussion

Microbiological data for each point of observation are presented in a diagram, showing a cross-section of the area (Fig. 3.6.3b). The counts indicate a marked decrease in PCA and EMB numbers with increasing distance from the system. At

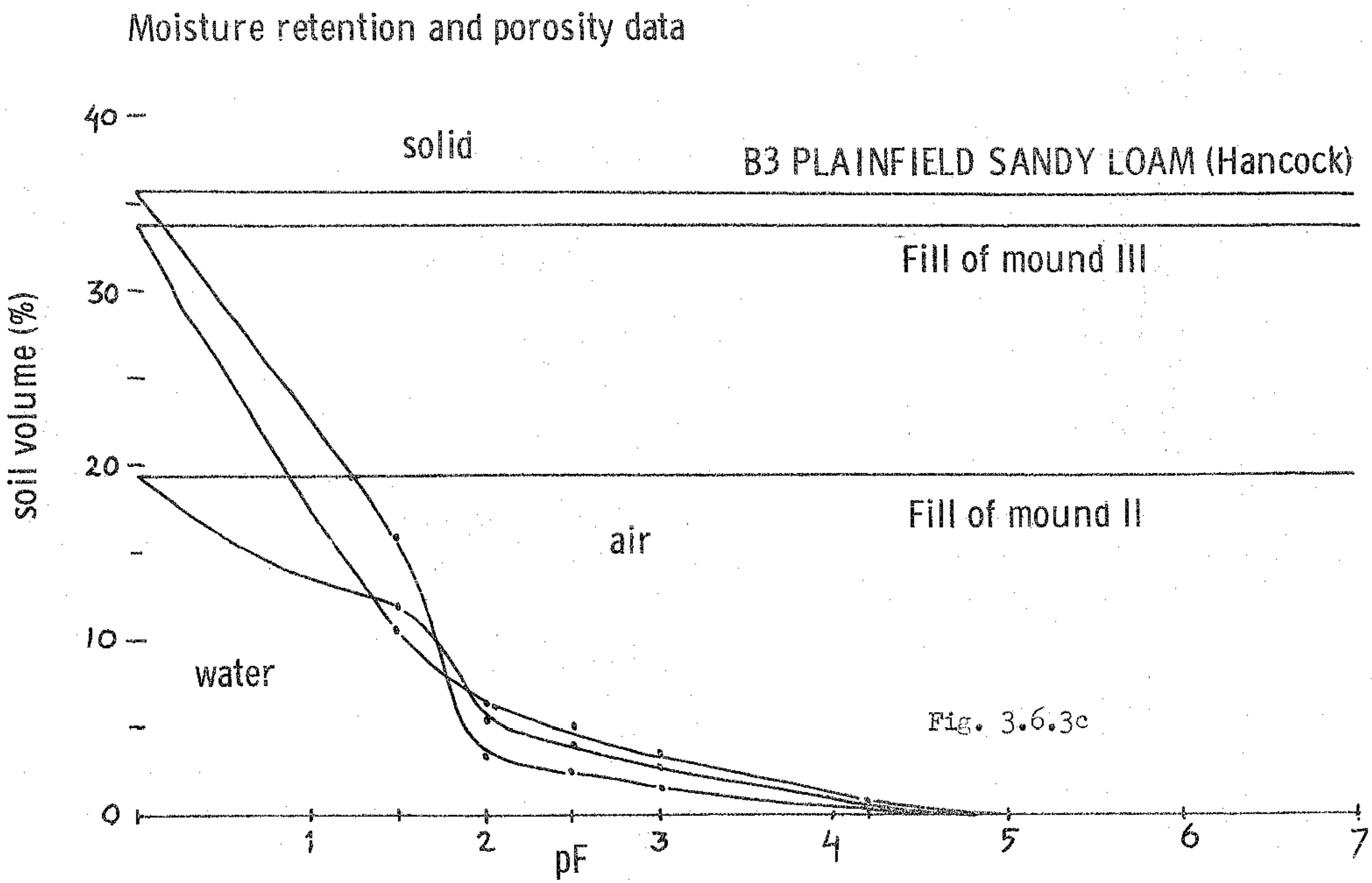
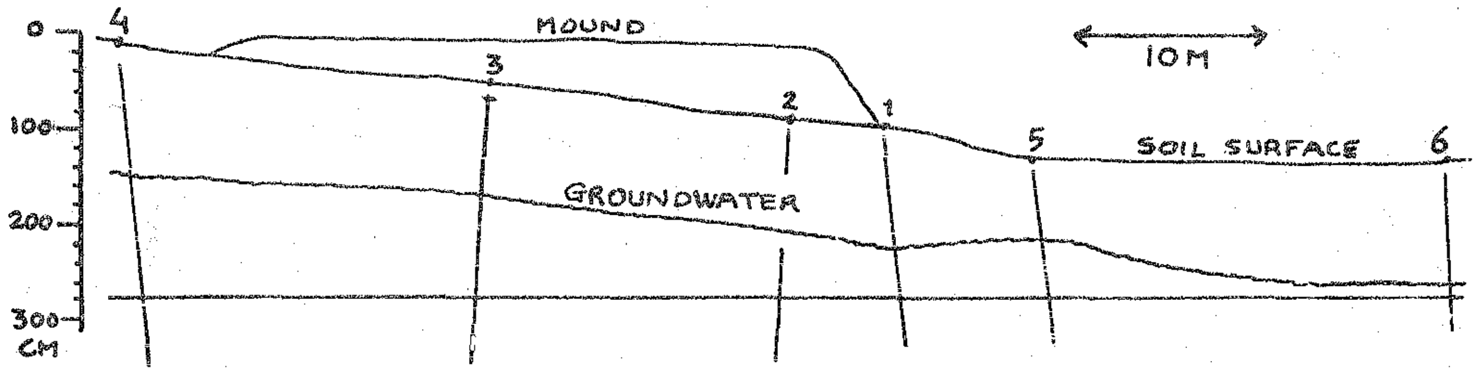

Moisture retention and porosity data
40
30
20
10
0
soil volume (%)
solid
B3 PLAINFIELD SANDY LOAM (Hancock)
Fill of mound III
Fill of mound II
air
water
1
2
3
4
5
6
7
pF

Fig. 3.6.3c

MOUND SYSTEM II Section of landscape with sampling points



MOUND SYSTEM II Section of landscape with sampling points

Fig. 3.6.3b

	4	WATERWELL	3	SEPTIC TANK	2	1	5	6
E.M.B.	0	0	>300	$>44\times10^3$	50	80	0	800
P.C.A.	1.6×10^4	21×10^2	10^5	22×10^6	22×10^4	15×10^4	2.3×10^4	44×10^4
m-ENTEROCOCCUS	0	1	39	20	0	0	0	10–100

(ORGANISMS PER ML)

Results of bacteriological analyses of groundwater, wellwater and septic tank effluent.

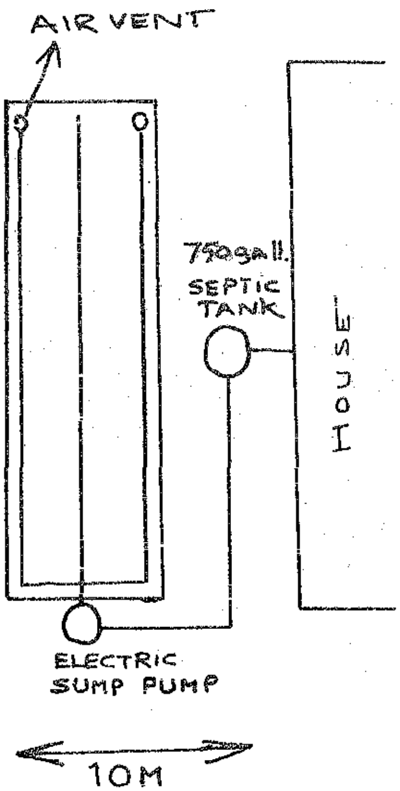
point 5 levels as low as those at point 4 upslope were determined. The streptococcus observed in the groundwater at point 6, may have originated from young cattle and did not percolate from the system. The soil auger used to make the holes, may have introduced organisms in the water from the contaminated topsoil. Considerable amounts of organic P and NO_3 are present in the groundwater (Table 3.6.3) as was the case in System I. However, the content of organic P at point 4 is as high as at the lower-lying other points. It is assumed that this high P content is probably not associated with the mound disposal system. Movement of nitrates from the system is indicated by increases in contents of nitrate down-slope from point 4 to point 1. Content of NH_4 was very high in the liquid of the septic tank, where most of the N is in the form of ammonia because of the anaerobic environment. After the owner has extended the mound to full size the only other factor that may still interfere with the proper functioning of this system may be clogging of the interface

Table 3.6.3. Nutrient content of groundwater, wellwater and septic tank effluent.

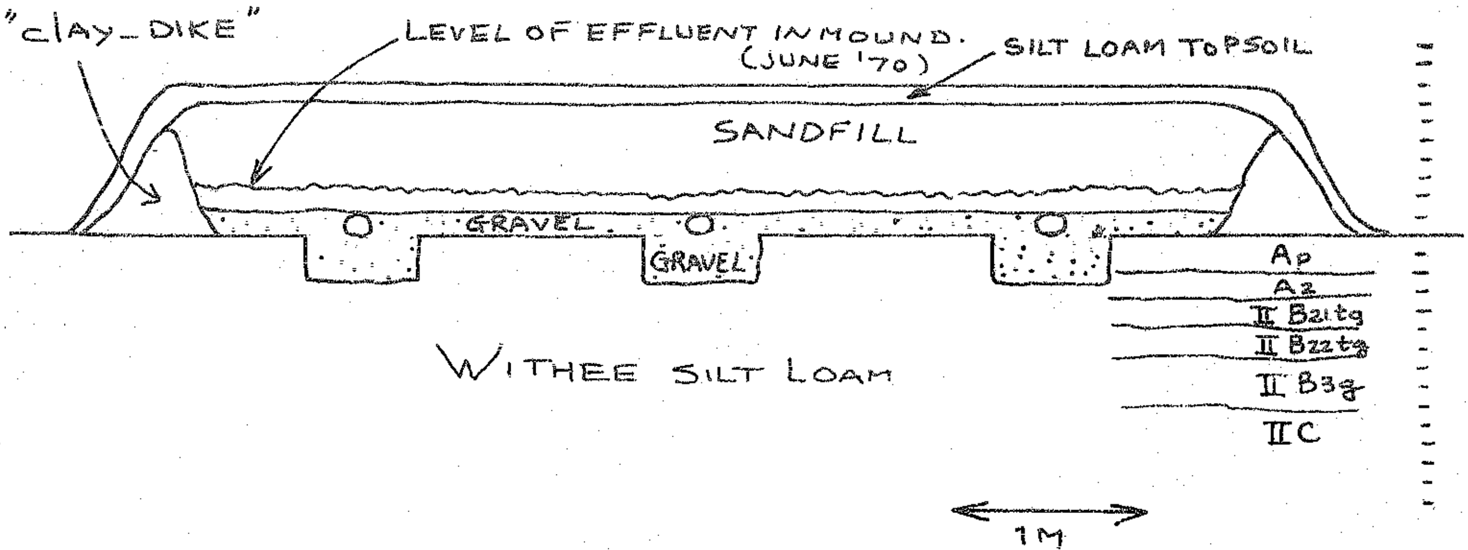
Sample No.	Total P ppm	Inorganic P ppm	Organic P ppm	NO_3 ppm	NH_4 ppm
1	8.0	.20	7.80	9.2	10.8
2	7.5	.25	7.25	7.8	6.0
3	9.0	.20	8.80	3.6	2.4
4	9.4	.15	9.25	.6	1.6
5	8.0	.30	7.70	5.6	1.2
6	0.3	1.0	7.30	5.6	---
Well water	9.0	.25	8.75	.2	.4
Septic tank liquid	9.2	---	---	.9	42.0

between the trench and the IVC horizon. The absorptive area of the field is approximately 600 sq. ft. ($54m^2$). At a loading rate of 450 gallons/day, a minimum vertical flow rate of 3.3 cm/day is necessary to avoid overloading.

SOIL ABSORPTION SYSTEM: MOUND SYSTEM III (Willard, wis)



top view of mound



section of mound

Fig. 3.6.4a

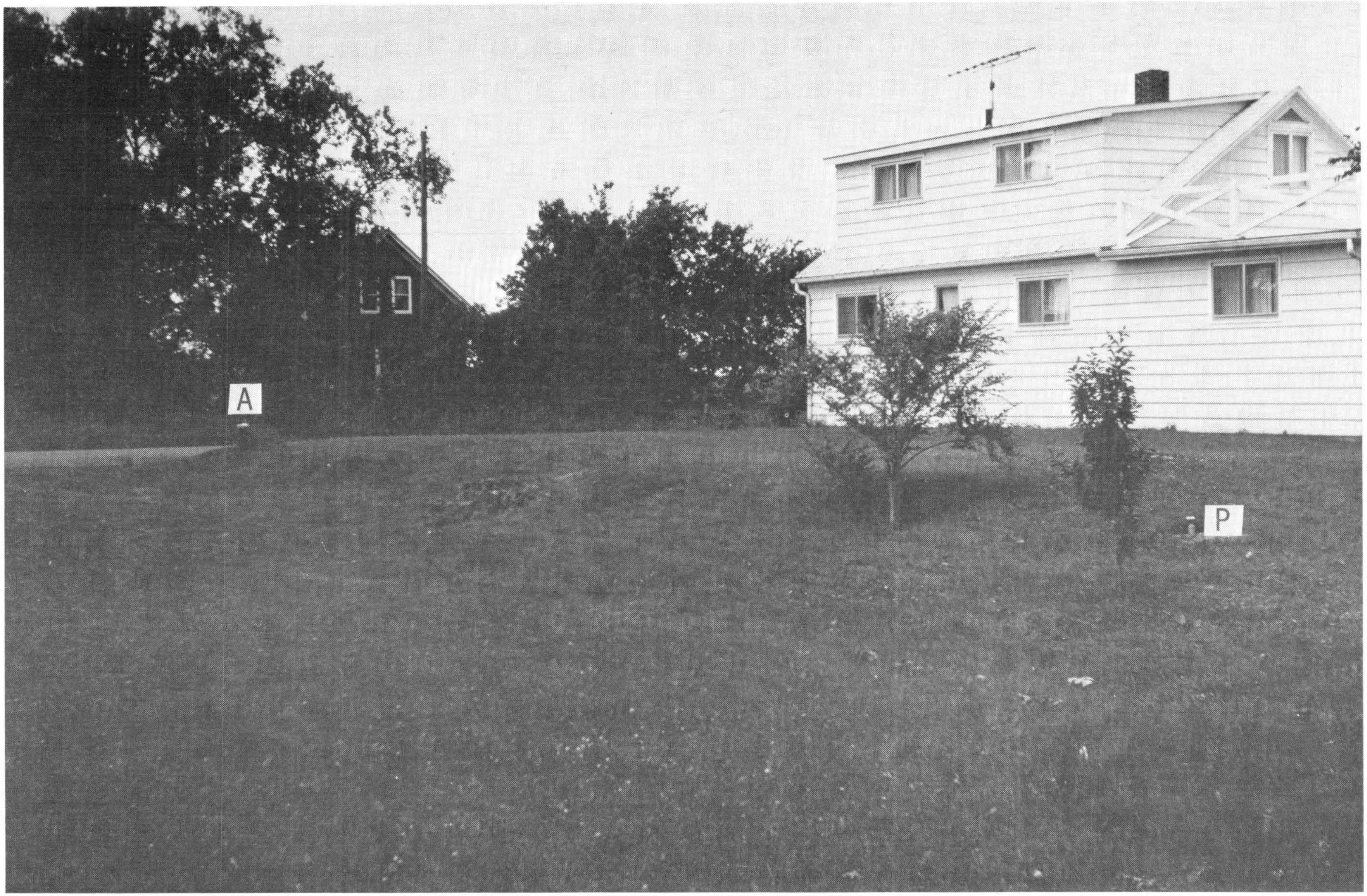


Photo 3.6.4 Mound System III.
This mound has a flat top. The effluent is pumped into the mound by an electric pump (P).
The air vent (A) marks the limit of the system (see diagram of the system, Figure 3.6.4a).

No hydraulic conductivity (K) by crust test is available yet for the white sand. Assuming, however, that it is close to that of the C horizon of the Plainfield loamy sand at the Hancock Agricultural Experiment Station, this flow rate (≈ K when the vertical gradient is unity) would correspond to a suction below the mound in the IVC horizon of about 20 mb. The test results in the C horizon of the Plainfield loamy sand near Friendship, Wisconsin (Chapter 3.4) showed a suction of about 20 mb around trenches with crusted walls. As long as the suction is lower than this value, difficulties are not likely to occur. Increasing the size of the field would help if suctions became higher than ± 20 mb. The system will be investigated again in the next season.

3.6.4. Mound System III on Withee silt loam (somewhat poorly drained, with tight subsoil)

3.6.4.1. Introduction

This system was constructed on a Withee silt loam in the fall of 1969. This relatively impermeable soil type, extensive in northcentral Wisconsin, formed in a silt loam cover over compact glacial till (see profile description). A top view and cross section of the mound are in Fig. 3.6.4a (see also Photo 3.6.4). The mound was about 80 cm high. A layer of 15 cm of coarse gravel resting on the soil surface was covered with about 60 cm coarse sand and 15 cm silt loam soil over that. The whole mound was surrounded by a so called "clay dike", to avoid seepage through the side of the mound. The tile lines were in the layer of gravel. Effluent had to be pumped from the low level of the outlet in the septic tank into these lines. It is evident that this system, like the other two, is not an ideal Mound System (see 3.6.1) because the tile lines are near the bottom of the mound. Analytical data are given in Section 3.1.3 for the Withee silt loam pedon at the University of Wisconsin Agricultural Experimental Station at Marshfield. Physical properties of the sand fill in the mound are in Fig. 3.6.3c. Studies were made in June 1970, when the soil around the system was very wet. The water table was found at about 100 cm below the surface at a distance of 3m from the mound. Next to the mound, the water level was at 30 cm. A sample of the liquid in the mound was taken on July, 30, when the environmental conditions were quite different. Then, free water did not accumulate in an auger hole of 1.50 m depth. The loading rate of this system was estimated to be about 120 gallons/day. The septic tank had to be pumped out once during the previous winter because of freezing problems. No other problems were reported.

3.6.4.2. Results and discussion

Bouwer double tube tests in the topsoil of the Withee soil were unsuccessful. The combination of a porous conductive topsoil and a dense impermeable B horizon, led to "boil-outs" in seven attempts. Therefore, large cores were taken, and K values determined from them. Results (Table 3.6.4.2) indicate that the

Table 3.6.4.2. Hydraulic conductivities of soil horizons determined on soil cores of a Withee silt loam pedon (Mound System III).

Horizon	K (cm/day)
Ap in soil next to mound	320 cm/day
Buried Ap below mound	300 cm/day
A2 in soil next to mound	7 cm/day
Buried A2 below mound	3 cm/day
II B2tg horizon	0.3 cm/day

porous and channeled topsoil has a very high conductivity. Very low values were measured in the B2 horizons. Results show clearly that at least 30 cm of relatively permeable soil is present over the dense, practically impermeable till. K values for a nearby Ap were the same as those of the Ap buried beneath the mound. The permeable topsoil is important for conducting liquid laterally away from the system, providing hydraulic gradients are sufficiently large.

The topsoil of the Withee silt loam at the Marshfield Station had a lower conductivity (Chapter 3.1), because of compaction. Previous land use, that determines the structure and physical properties of the topsoil, is therefore a factor to be considered in site evaluation. Additional data, particularly of the situation in early spring, is needed before this system can be completely evaluated.

In a level soil with such impeded drainage, horizontal hydraulic gradients in the topsoil can be expected to be low. Assuming a suction in the topsoil of 30 mb, we can make the following calculation. Moisture retention data show that about 5% of the soil volume becomes filled with air when soil moisture suction increases from 0 (saturation) to 30 mbar (pF1.5). Given an absorptive area directly below the mound of 106 m^2 and a topsoil depth of 30 cm, a volume of only 1600 liters (= 400 gallons) could be absorbed by the soil. Once the soil were saturated, the liquid would have to seep away laterally and downward. The underlying B horizon (K_{sat} = 3 mm/day) could absorb only about 75 gallons/day. The remaining 50 gallons would have to move laterally. Saturated K values (varying from 300 cm/day in the A1 to 3 cm/day in the A2) are sufficiently high to allow this, but the hydraulic gradients may be too low. As a result, liquid may fill the mound, which then serves as a holding tank. The water holding capacity of the mound is 7300 gallons, (calculated by multiplying the cross sectional area, 4.56 m^2, by the length, 19 m and by the porosity, 0.34). This is a large amount of effluent, equivalent to the out-put of effluent in a period of over two months.

Further measurements of the hydraulic conditions at the site are needed to determine real flow rates in different seasons, height of the water table, the effects of freezing of the soil and of continuous ponding of liquid in the mound.

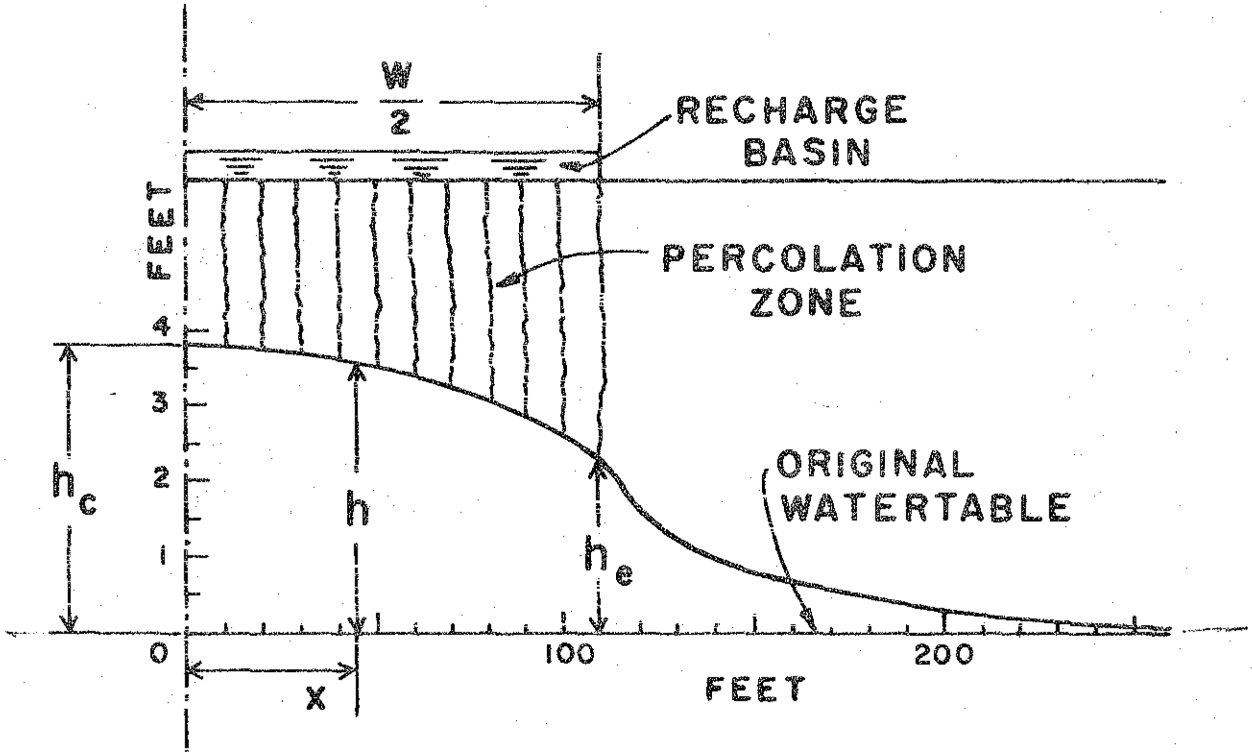


Fig 3.6.5 Geometry and symbols for ground water mound (from: Bouwer, 1970)

3.6.5. The position of the groundwater below mound systems*

A mound system can only function properly when the groundwater (sometimes stagnant water on top of an impermeable layer) does not rise close to the soil surface or into the mound itself, due to the continuous addition of downward percolating effluent from the mound. Movement of groundwater and the shape of the water table below the mound are a function of: 1) loading rate, 2) dimensions of both mound and ground water body,

3) depth of the impermeable layer, 4) conductivity distribution throughout the mound-groundwater system, and 5) gradients in the groundwater system.

In mound systems, where soil boundaries restrict the direction of flow to an approximately horizontal direction in the topsoil, certain approximations, like the one of Dupuit-Forchheimer (Bouwer, 1970, Childs, 1969), can be used to describe the flow of groundwater in quantitative terms. Fig. 3.6.5 (from: Bouwer, 1970) gives a cross section of a recharge basin (that could be the bottom of a mound) with width W, on top of a homogeneous soil profile where the original groundwater was at 6 feet depth. Due to the addition of liquid from the mound, the level of the groundwater is at 2 feet below the surface at the center of the basin. The hydraulic properties of the aquifer can be expressed in terms of the transmissibility coefficient T (= hydraulic conductivity x aquifer height). The transmissibility of the system may not be the same as that for the full height of the aquifer between watertable and impermeable layer. This is because most of the flow takes place in the upper region of the aquifer. Thus it is necessary to use an effective transmissibility if the flow system is to be treated on the basis of the horizontal flow assumption. Steady flow below the watertable on top of the B can be described with the Dupuit-Forchheimer assumption of horizontal flow as follows:

$$I \cdot x = T_e \cdot \frac{dh}{dx} \quad (1)$$

*The authors are indebted to Dr. C. R. Amerman for helpful suggestions.

where I = infiltration rate for recharge area, x = horizontal distance from centerline of recharge area, T_e effective transmissibility of aquifer, h = height of groundwater mound above static water table (see Fig. 3.6.5). $I \cdot x = q$ (= horizontal flow rate per unit width across a plane perpendicular to direction of flow at distance x from the center of the flow system of infinite length). Integrating between x = 0 and x = w/2 yields:

$$h_c - h_e = \frac{I \cdot W^2}{8\,T_e} \quad (2)$$

where h_c = h at center of mound (x = 0), h_e = h at edge of mound (x = w/2) W = width of recharge area.

The effective transmissibility (T_e) can be determined by electrical analog procedures when K is known or by determining all factors, except T_e in equation (2).

Example: In June, 1970 the following values were measured in Mound System III: h_c = 90 cm, h_e = 70 cm (water table in surrounding soil was at 100 cm; below the mound at 10 and at the sides at 30 cm below the surface). I was estimated at 0.33 cm/day (loading rate = 100 gallons/day, absorptive surface 20 x 6 = 120 m^2), W = 600 cm. It follows T_e = 742.5 cm^2/day. Average K for the topsoil is 15 cm/day. The effective height of the aquifer, therefore, would be 50 cm, which agrees well with the measured K values and the location of the B2tg horizon in the profile. Knowing T_e for a flow system, makes possible series of calculations, varying I, W and h_c and h_e. The width of the mound (W) is a very important parameter in such calculations, as it occurs squared. This points to the general necessity to build long, elongated mounds rather than short and broad ones,so as to increase I, with the other parameters constant. Finally, the calculations assume that water can move away laterally through the topsoil around the system. Building a system in a low, concave area will lead to difficulties as liquid accumulates

SCHEMATIC CROSS SECTION OF A MOUND SYSTEM

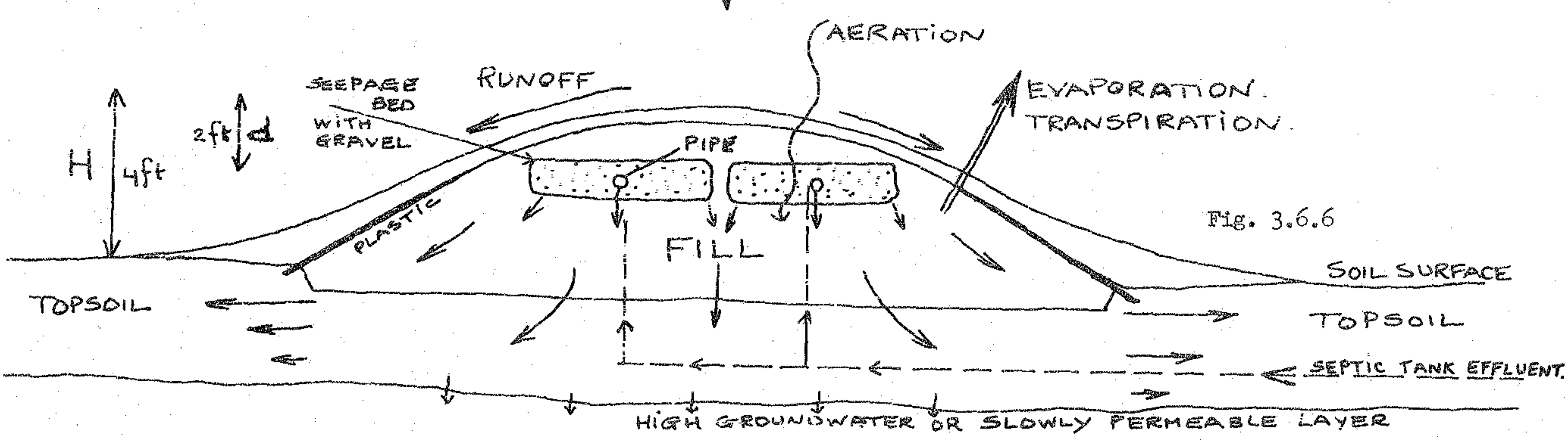
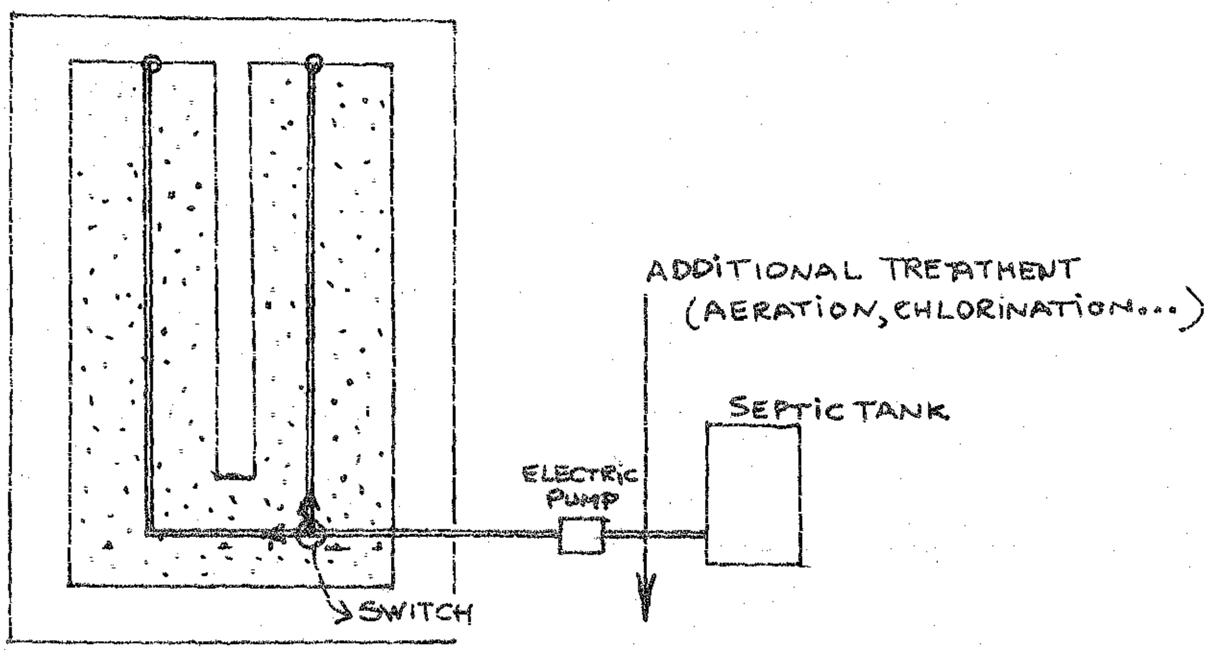


Fig. 3.6.6

top view



without possible drainage. Mound systems should preferably be constructed upslope on gentle slopes. Next fieldseason, we will pay special attention to the groundwater level below and around mound systems.

3.6.6. Discussion and preliminary conclusions

The limited amount of data available suggest that properly constructed mound systems may be an answer to the problem of liquid waste disposal on sites unsuitable for a conventional buried system. However, it is too early for a positive conclusion at this time. Research will be continued, based on the following propositions, tentative suggestions for design, and on the experience obtained in studying these three mounds and several conventional liquid waste disposal systems.

Fig. 3.6.6 shows what a "standard" mound system would be like. The moisture content in the mound at any time would be the resultant of:

1. Addition of liquid to the mound as:
   1.1. effluent pumped from the septic tank;
   1.2. rain water or melted snow percolating through the top and sides of the mound.
2. Loss of liquid from the mound by:
   2.1. flow into and through the undistrubed natural profile below the mound;
   2.2. evaporation at the surface of the mound;
   2.3. transpiration by plants growing on the top and sides of the mound.

A mound system works well when:

1. The effect of processes of group 2 exceeds that of processes of category 1.
2. The effluent, moving into the soil as indicated in category 2.1, does not move to the soil surface, into lakes or streams or wells, before harmful microorganisms and excessive amounts of nutrients have been eliminated in the soil

Item 1.1. The effluent from the septic tank can be the usual untreated liquid resulting from a process of anaerobic digestion, or it can be aerated or chlorinated before entering the mound. Aeration would be advantageous, particularly in marginal systems like this one, insofar as it reduces clogging problems and the duration of the necessary cleaning treatment in the soil. Microbiological data are needed to justify a definite recommendation that the added cost of installing an aeration treatment facility be considered seriously. Pumping of effluent into the mound will always be necessary. This introduces the practical possibility of dosing (as discussed in Chapter 3.2), to reduce the incidence of anaerobic conditions in the fill material of the mound. All lines in a system can be dosed equally or subsystems may be constructed (see Fig. 3.6.6) such that one of the lines can be closed off temporarily while the other gets the full load. In this case, the seepage beds for each line can be separated to avoid interflow.

Finally, the pipes should be well protected to avoid freezing in winter. One possibility would be to bury the pipes and to lead them into the mound from below (Fig. 3.6.6).

Item 1.2. Since the Withee soil is a marginal disposer of liquid waste, any addition of liquid beyond the effluent itself, should be prevented. Infiltration of rain and snow melt water into the mound should be reduced to a minimum. Covering the mound with plastic would accomplish this but would also stop diffusion of air, which is essential for the breakdown of organic wastes. It is better, therefore, to give the top of the mound a convex shape, to accelerate runoff. A well developed vegetative cover would also help to reduce this type of infiltration through interception and transpiration.

Item 2.1. The effluent would flow from the pipe first into a bed filled with coarse gravel, then into about 3 feet of fill soil. The upper soil horizon of the natural soil below the fill may be excavated slightly to enlarge the area of contact of fill and soil. The purpose of the 15 cm (6")-thick gravel bed is to avoid plugging of fill immediately around the pipe and to enlarge the area of contact with the fill material.

The choice of fill material is an important one. Coarse sands are commonly used, probably because saturated K values of such materials are very high. However, a very sharp drop in K occurs when the fill material becomes unsaturated as a result of crust formation (see Section 3.4). Loamy sand or sandy loam would be a better choice for fill because although they have lower K_{sat} than sand, they have much higher unsaturated K values at the suctions of 20 to 40 mbar that may be expected to occur below the gravel bed after crusts have formed. For example, a sandy loam till (Section 3.2) would be a better choice than a Plainfield sand (Sec. 3.4; see conductivity curves of both materials in Section 2.3).

The amount of flow into the fill and into the soil below the mound will be related to the dosing procedure (Section 3.2), as discussed in Item 1.1. Flow into the slowly permeable subsoil horizons and, particularly, lateral horizontal flow are very important, since their magnitude will determine whether or not the groundwater will rise sufficiently to change the hydraulic properties of the flow system. If the water is not removed fast enough, effluent will back up into the mound and be stored there. This may be useful for short periods of unusually high loading or wet soil conditions. However, treatment of the effluent is based on oxidation of organic compounds in the sewage as it occurs during processes of unsaturated flow. The mound is not meant to act as a "storage tank", and to use it as such is to misuse it. Flow conditions will be governed by physical constants (as measured by crust and clod tests) and boundary conditions. The general slope of the area and the location of the site on the slope will be of importance. Only a quantitative analysis of the physical processes involved will yield reliable results for predicting the future behaviour of any system (see Section 4).

Item 2.2. The rate of evaporation will primarily be a function of the weather. Three aspects are important (Rose, 1966):

1. There must be supply of heat to provide the quite large latent heat of vaporization (590 cal g^{-1} at $15^{o}C$).

2. The vapour pressure in the overlying air must be maintained at less than that at the evaporating surface, since evaporation is zero when there is no gradient in vapour pressure. This points, aside from air humidity, also to the importance of mixing action of the wind. Scattered trees in an area may give rise to turbulent air movement, as does an elevated mound on the soil surface.

3. Sufficient water must continue to be available for evaporation, this being a limiting factor under dry conditions. Hydraulic properties of soil determine this factor. The height of capillary rise of liquid in a porous medium is a function of pore, and therefore, particle size. Rode (1962) gives the following simple relationship: $H = 15/r$, where H = capillary rise (cm) and r = radius of capillary (cm), assuming complete wetting of the walls of the capillaries. For homogeneous soils the diameter of the capillaries may be replaced by the average radius of the soil particles d (cm) so that $H = 75/d$. Rode compared his observations with the values, determined much earlier by Atterberg (1908) for various textures (Table 3.6.6a) and found satisfactory agreement.

Table 3.6.6a Particle size and capillary rise.

Particle Size (mm)	Max. Capillary Rise (mm)	
	observed	calculated
5-2	25	21
2-1	65	50
1-0.5	131	100
0.5-0.2	246	210
0.2-0.1	428	500
0.1-0.05	1055	1000
0.05-0.02	2000	2100

The formula is not valid for heavy textured soils. This is due to the merging of films of sorbed water on opposite pore walls, making capillary rise impossible. The table shows that use of a very fine sand-fill (0.1-0.05 mm) in a mound, would be unfavorable since all pores would fill with liquid up to a height of one meter, leaving no air to be used for purification of effluent. A very coarse sand would be better from the standpoint of aeration. However, conductivity values in such materials decrease very sharply as soil moisture tension increases. The effect would be less evaporation. More reliable conclusions can be reached when hydraulic conductivity (K) data of different soil materials are considered (Section 2.3). At suctions of around 80 mbar (which is about the tension of the moisture in the top of the mound when liquid is standing at the bottom at 80 cm below the top), K values should still amount to a few mm per day to enable evaporation of a sizable amount of liquid. The values in Table 3.6.6b show that only the stony sandy loam and, less so, the silt loam satisfy this condition. Sands are much less suitable as fill materials since conductivity falls down abruptly with increasing soil moisture tension.

Table 3.6.6b. Hydraulic conductivity (K)at 80mb for four soil materials (Sec. 2.3).

Soil Materials	K (at 80 mb)
Stony sandy loam (Sec. 3.2)	3 mm/day
Silt loam B2	1 mm/day
Sand (Sec. 3.4)	0.08 mm/day
Clay (Sec. 3.3)	0.06 mm/day

Another advantage of the stony sandy loam is its very heterogeneous porosity, consisting of large and fine pores (see frontispiece). So in addition to favorable capillary properties also purification of effluent by oxidation can occur at the same time (see Section 3.2). Stony sandy loam soil material is abundantly available in the State, where it occurs as extensive glacial till sediments.

Item 2.3. Transpiration of plants may be important for the removal of liquid from the system. Unfortunately, this mechanism works best in the growing season of the year, when the other processes of liquid removal are most active as well. Table 3.6.6c gives precipitation and potential evapotranspiration (inches) at Madison, Wisconsin, (Tanner*).

Table 3.6.6c. Precipitation and potential evaporation in Madison, Wisconsin.

Month	J	F	M	A	M	J	J	A	S	O	N	D
Precip. (in)	1.3	1.1	1.8	2.5	3.3	4.0	3.3	2.9	4.0	2.1	2.3	1.4
PE (in)	0.2	0.5	1.3	2.9	4.2	5.4	5.9	4.5	3.2	1.8	0.6	0.2

It is estimated that transpiration of plants can remove about 5 mm of liquid per day in July, but only 5 mm per month in December. The type of vegetation is very important for the extraction of soil moisture (Table 3.6.6d).

*From lecture notes of Professor C. B. Tanner, University of Wisconsin, Department of Soil Science, Madison.

Table 3.6.6d. Land use and annual evapotranspiration (Tanner*)

Water	29-32 inches (evaporation only)
Forest	25-30 inches
Alfalfa-brome	22-26 inches
Corn	18-22 inches
Grain with seeding	18-22 inches
Bluegrass	15-19 inches
Bare soil	12-18 inches (evaporation only)

Every mound system should be seeded with deep rooting grasses, and attempts should be made to grow alfalfa. Shrubs and trees growing on top of mounds seems to be less desirable,since their roots may grow into and disrupt tile lines. However, it would be highly advantageous to grow trees on the soil surrounding the mound, thus strongly increasing the potential lateral flow away from the system.

The final requirement of a septic system is that it purify the effluent. More has to be learned about how this is accomplished, but we may assume that effluent must move downward through unsaturated soil for at least several feet, then by lateral subsurface movement in the groundwater of a few hundred feet (Bouwer, 1968). Local hydrological conditions will determine the flow patterns. Surface seepage of effluent next to the mound can be avoided by covering the lower sides with a clay layer and a sheet of black plastic (Fig. 3.6.6).

*From the lecture notes of Professor C. B. Tanner, Soil Science Department, University of Wisconsin, Madison.

4. Evaluation and plans for future work

1. Purposes of this project are:

   a. To develop procedures to monitor and evaluate current performance of liquid waste disposal septic system.

   b. To develop procedures to test prospective soils as to their suitability for on-site liquid waste disposal;

   c. Development of design and management criteria for adequate septic systems on a wide variety of soils, including some soils that are disqualified by current test procedures.

A. MONITORING OPERATING SYSTEMS

The following procedures have been used successfully in this study to characterize the actual performance of a system at any given time:

1. Tensiometry for measuring soil moisture tensions around seepage beds.
2. Microbiological and chemical analyses of effluent in trenches and percolates sampled at different distances from the seepage bed.

   Discussion: In addition consideration must be given to the level and dynamics of the ground water in the vicinity of a system. Properties of any system vary within a specific range as a function of system management. Monitoring at a certain time gives only one state in such a range. A true quantitative evaluation of all potential properties of a system can only be achieved when measurements of Group B are also made.

B. DETERMINING HYDRAULIC SITE CHARACTERISTICS

Hydrological and physical properties of any soil horizon to be used for liquid waste disposal can be determined by:

1. The crust test procedure for measuring hydraulic conductivity (K) of unsaturated soil. The resulting information makes possible the estimation of infiltration rates as a function of crust resistance.

2. The Bouwer test for measuring K of saturated soil. This value gives the maximum infiltration rate.

3. The Saran-clod method for measuring moisture retention properties, porosity, bulk density and COLE values. With these data air contents of the soil can be determined at different suctions.

<u>Discussion</u>: Additional information is necessary on two points:

1. Boundary conditions of the system (level of the ground water, depth to soil horizons in the aquifer, and properties of these horizons).
2. The relationship of biogenic crust development and resistance to expected loading rates, effluent quality and air diffusion in the soil. One example studied (Sec. 3.2) showed that after a week high suctions (80 mb) developed below a bed filled with effluent at a depth of 90 cm in sandy loam till, due to formation of a crust with a high hydraulic resistance. Another example (Sec. 3.4) showed a lower suction of 20 mb below a system filled with effluent in sand at a depth of 70 cm, apparently because of a less resistant crust. The degree of crust development, as a function of dosing, effluent quality and air diffusion in the soil, will determine the effective percolation rate of effluent into the soil. Such percolation is a process of two dimensional flow, that can be solved analytically for varying boundary conditions, by using computer programs. Results of such an analysis will apply to a two dimensional representative cross section of a bed. The next step would be to design the whole (three dimensional) system.

C. CONSIDERATIONS FOR SEPTIC SYSTEM CONSTRUCTION AND MANAGEMENT

Size and shape of systems can be determined on the basis of analyses as described under B, above. The loading regime and possibly even effluent quality and quantity will have to be manipulated in such a way that an optimal crust resistance results. An optimal resistance is defined as being sufficiently low to enable significant infiltration of effluent into the soil, but sufficiently high to result in bacteriological purification of effluent within a distance of a few feet. The problem of chemical pollution needs additional study. Any optimal crust resistance will result in a certain unsaturated K value, as independently determined by the crust test for the same soil horizon. Dimensions of the system can then be based on this K, with the addition of a safety margin of possibly 10 percent. This type of analysis applies to mound systems as well as to conventional systems.

2. Proposals for future work

In view of data reported in the literature and of experience in this project in Wisconsin, the following work is proposed for the immediate future:

1. Investigation and monitoring, using methods described in this report and a continuing study of systems already investigated, including mound systems.

2. Collection of quantitative information in these systems on crust resistance as a function of dosing, quality of effluent (including effects of aeration chambers) and air diffusion in the soil. This information will be supplemented by results from column studies in the bacteriology laboratory.

3. Development of a computer program, in cooperation with USDA Agricultural Research Service for two dimensional flow around seepage trenches as a function of varying boundary conditions, and soil type. Effect on level of groundwater below and around septic systems by additions of liquid from them may be incorporated into such programs, or can be approximated by separate procedures as described in the literature (Dupuit-Forchheimer assumptions).

4. Continuation of studies of biological purification of effluents through soil absorption both in soil columns in the laboratory and in the field (in cooperation with the Department of Bacteriology).

5. Collection of more data on chemical pollution (NO_3, Cl, and P) caused by private septic tank systems, and exploration of means to minimize this danger.

6. Measurement of soil temperatures around seepage fields and in mound systems in the winter.

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Appendix 6.1. Profile descriptions and particle size analyses**.

PEDON:# Near Marshfield, (see Section 3.1) and pedon underlying the Mound System III (see Section 3.6.4).

LOCATION: Marshfield Agricultural Experimental Station, idle ground near barn in the SW$\frac{1}{4}$, SE$\frac{1}{4}$, Sec. 15, T25N, R3E.

DATE OF DESCRIPTION: June 8, 1970.

PROFILE DESCRIBED BY: J. Bouma, W. Walker, D. J. VanRooyen.

PARENT MATERIAL: Loess over acid glacial till.

PHYSIOGRAPHY: Gently undulating glacial morainic landscape, underlain at about 30 feet by Precambrian crystalline (granitic) rocks.

DRAINAGE CLASS: Somewhat poorly drained.

SLOPE AND ASPECT: 0-1% east.

EROSION: No observable erosion: Soil is protected by present dense vegetative cover.

VEGETATIVE COVER: Waste land covered with weeds.

CLASSIFICATION: Aquic Glossoboralf; fine-loamy, mixed, frigid; Withee silt loam.

PEDON DESCRIPTION

Horizon & Depth (cm)	Observations
Ap 0-18	Very dark grayish brown (10YR 3/2)* when broken, dark brown (10YR 4/3) when rubbed; silt loam; strong fine platy; firm; common clear discontinuous dark reddish brown (5YR 3/4) ferrans along planar voids; fine few (2%) rounded black manganese-concretions; roots tend to follow vertical cracks into B-horizon; pH 4.5; abrupt and smooth boundary.
A2g 18-27	Brown (10YR 5/3) when broken and rubbed; silt loam; moderate medium prisms breaking into moderate fine plates; firm; common faint yellowish red (5YR 5/8) mottles; upper horizon ferrans like those in the Ap and few prominent vertically elongated mottles along root channels extend into the B1; pH 4.5; gradual wavy boundary.
B1 27-37	Reddish brown (5YR 5/3) when rubbed and pale brown (10YR 6/3) when broken; silt loam with pockets of silt loam and a few pebbles; moderate medium prisms breaking into moderate fine plates; firm; pH 4.2; gradual wavy boundary.

**All particle size analyses were made by D. J. VanRooyen.

Horizon & Depth (cm)	Observations
IIB2tg 27-50	Dark brown (7.5YR 3/3) to grayish brown (10YR 5/2) when broken and brown (10YR 5/3) when rubbed; loam with few pebbles; moderate medium prismatic breaking into moderate medium plates; firm; discontinuous skeletans evident on larger ped faces; pH 4.2; smooth and gradual boundary.
IIB22tg 50-63	Dark reddish brown (5YR 3/4) to dark brown (7.5YR 4/3) when broken and yellowish red (5YR 4/8) when rubbed; loam; moderate coarse primsm breaking into moderate medium plates; firm; few faint brown (7.5YR 5/4) mottles on planar faces; discontinuous skeletans evident on larger ped faces; pH 4.2; smooth and gradual boundary.
IIB3g 63-120	Dark reddish brown (2.5YR 3/6)+ when broken; strong brown (7.5YR 4/6)+ when rubbed; clay loam with coarse and very coarse sand pockets; very coarse prismatic structure breaking into weak coarse plates; pockets with coarse and very coarse sand have weak coarse platy structure; firm; few faint fine light gray (2.5Y 7/2)* mottles along root channels; pH 4.1; smooth and gradual boundary.
C 120+	Reddish brown (5YR 4/6) with mottles of olive gray (2.5YR 5/1) when broken; sandy clay loam; weak very coarse prismatic; slightly plastic to sticky; pH 4.3.

*Munsell color designations are for moist soil unless stated otherwise.

#See Figure 3.3.3 for location.

+Color and notation from the Japanese Standard Soil Color Chart.

Particle size distribution, Withee silt loam.

	VCS	C.S.	M.S.	F.S.	V.F.S.	C.Si.	M.Si.	F.Si.	Clay	Total
Ap	Tr	1.40	4.90	5.70	14.90	21.00	24.00	9.00	19.50	100.00
A2g	Tr	1.10	2.80	2.50	14.10	17.50	27.50	8.50	21.00	100.00
B1	0.6	1.60	5.00	4.70	14.60	22.00	28.00	10.50	13.00	100.00
IIB21tg	Tr	0.50	7.80	9.50	9.70	13.50	18.50	7.00	22.50	100.00
IIB22tg	Tr	1.40	7.20	7.20	16.70	17.00	19.00	8.00	23.50	100.00
IIB3g	Tr	1.70	8.50	9.00	12.30	16.00	8.50	8.50	29.50	100.00
C	0.2	2.30	14.20	13.50	20.50	11.00	5.00	6.00	19.50	100.00

PEDON: Near Arlington, Wisconsin (see Section 3.2).

LOCATION: This site is on the U.W. Arlington Agricultural Experiment Station, about 50 feet east of the fence east of the house on the Poultry Farm in a cultivated corn field.

DATE OF DESCRIPTION: July 16, 1970 by D. J. VanRooyen and W. Walker.

PARENT MATERIAL: Loess over a dolomitic sandy loam glacial till.

PHYSIOGRAPHY: Rolling to hilly glacial landscape underlain by Ordovician Prairie du Chien dolomite (limestone).

DRAINAGE CLASS: Well drained.

SLOPE AND ASPECT: About 4% east.

VEGETATIVE COVER: Field corn at time of description.

GROUNDWATER: Not observed within depth of sampling (180 cm).

CLASSIFICATION: Typic Arguidoll; fine silty, mixed, mesic; Saybrook silt loam.

PEDON DESCRIPTION

Horizon & Depth (cm)	Observations
Ap 0-20	Very dark brown (10YR 2/2)+, silt loam; weak medium subangular blocky; firm; abrupt smooth boundary.
B21t 20-55	Dark brown (7.5YR 3/3)* when broken and brown (7.5YR 4/3)* when rubbed, silt loam; weak medium subangular blocky; firm; gradual, smooth boundary.
IIB22t 55-65	Dark brown (7.5YR 3/4)*, sandy loam; with few pebbles weak coarse subangular blocky; friable; gradual smooth boundary.
IIB3t 65-85	Brown to dark brown (7.5YR 4/4), sandy loam with pebbles; weak coarse subangular blocky; very friable gradual smooth boundary.
IIC >85	Dark yellowish brown (10YR 4/4), sandy loam with pebbles and bounlders; structureless; loose.

+Moist colors by Munsell Soil Color Chart unless otherwise stated.

*Moist colors by Japanese Standard Soil Color Chart.

Particle size distribution, Saybrook silt loam (Chapter 3.2)

	VCS	C.S.	M.S.	F.S.	V.F.S.	C.Si.	M.Si.	F.Si.	Clay	Total
Ap	0.5	1.5	3.5	4.5	2.5	23.5	34.0	9.5	20.5	100.00
B21t	0.5	1.5	5.0	9.0	4.0	19.5	32.5	10.0	18.0	100.00
IIB22t	1.5	5.0	14.5	33.5	13.5	8.5	11.0	3.0	9.5	100.00
IIC	1.3	4.0	25.5	24.7	20.1	13.0	6.0	2.0	5.0	100.00

PEDON: Near Ashland, Wisconsin (see Section 3.3).

DATE OF DESCRIPTION: August 7, 1970 by J. Bouma and D. J. VanRooyen.

PARENT MATERIAL: Red lacustrine clay, reworked and deposited as glacial till.

PHYSIOGRAPHY: The site is located on a 2% slope of a hilltop in an undulating landscape. A gulley (15% slope) is found at 10 m downslope from the air vent of the drainage bed.

DRAINAGE CLASS: Moderately well drained (which for purposes of liquid waste disposal must be translated as "poorly drained").

SLOPE: 1-2% N.

VEGETATIVE COVER: Grass. Original vegetation was northern mixed coniferous--hardwood forest.

GROUNDWATER: Not observed within the depth of pit (120 cm).

CLASSIFICATION: Typic Eutroboralf, (Gray Wooded soil) very fine, mixed frigid; Ontonagon silty clay loam.

Ap 0-10	Reddish brown (2.5YR 5/4)+ when broken and dull reddish brown (2.5YR 5/3)* when rubbed; silty clay loam; moderate fine subangular blocky; common faint discontinuous skeletans along ped faces; friable; smooth clear boundary.
A2 10-18	Reddish brown (2.5YR 5/4) when broken and rubbed; silty clay loam with a few small stones; moderate medium subangular blocky; locally lime deposit of silt size; skeletans coat surfaces of larger voids; few faint yellowish red (5YR 5/8) Fe-mottles along planar voids and root channels; friable; gradual wavy boundary.
B1 18-24	Dark yellowish brown (10YR 4/4) when broken and yellowish brown (10YR 5/4) when rubbed; clay loam with some small stones; moderate medium prismatic breaking to strong medium and fine angular blocky; few faint skeletans on ped faces; slightly hard; boundary smooth and gradual.
B21t 24-37	Reddish brown (2.5YR 4/4) when broken and rubbed; clay with small stones; strong very coarse prismatic breaking to strong medium prismatic breaking into strong medium angular blocky; slightly hard; gradual smooth boundary.
B22t 37-65	Red (2.5YR 4/6) when rubbed and broken; clay with pebbles and small stones; strong very coarse prismatic breaking to strong medium prismatic breaking to strong medium angular blocky with common fine (1-3 mm) grayish red (7.5R 6/2)* $CaCO_3$ - glaebules; hard when dry and sticky when wet; gradual and smooth boundary.

B3
65-120 Red (2.5YR 4/6) when broken and rubbed; clay; moderate coarse prismatic breaking into moderate medium angular blocky; color changes to weak red (10R 5/4) in the parts of the horizon that are rich in lime, with common fine (1-3 mm) grayish red (7.5R 6/2)* $CaCO_3$ - glaebules; hard; boundary smooth and gradual.

C
120+ Red (2.5YR 4/6) when broken and rubbed; clay strong coarse prismatic breaking into strong medium angular blocky. Olive gray (10Y 6/2) colors along root channels; with $CaCO_3$ glaebules; greenish coatings along ped faces; slightly hard.

+Moist colors by the Munsell notations unless otherwise stated.

*Moist colors as in the Japanese Standard Soil Color Chart.

Particle size distribution of B3 in Ontonagon clay (Chapter 3.3).

	VCS	C.S.	M.S.	F.S.	V.F.S.	C.Si.	M.Si.	F.Si.	Clay	Total
B3 (90cm)	0.2	1.4	4.6	5.8	13.0	4.0	12.0	12.5	46.5	100.00

PEDONS: Near Hancock and Friendship (see Section 3.4).

LOCATION: Hancock Experimental Station and private land near Friendship.

DATE OF DESCRIPTION: Sept. 17, 1970 by J. Bouma.

PARENT MATERIAL: Sandy sediments of glacial outwash and eolian origins.

PHYSIOGRAPHY: The area is nearly level to undulating.

DRAINAGE CLASS: Excessively drained.

SLOPE: 0-1%.

EROSION: No observable erosion, although soil was bare at moment of investigation.

CLASSIFICATION: Typic Udipsamment; sandy, mixed, mesic; Plainfield loamy sand.

Ap
10-26 Very dark grayish brown (10YR 3/2) loamy sand, apedal coherent structure resulting from intergranular bonds in the s-matrix; slightly firm; abrupt and smooth boundary.

B21
26-62 Strong brown (7.5YR 4/6) sand; structure as in Ap; friable; diffuse and smooth boundary.

B22
62-86 Strong brown (7.5YR 5/6) sand; single grain; loose; gradual and smooth boundary.

B3
86-110 Strong brown (7.5YR 5/8) sand; single grain; loose; gradual and smooth boundary.

C
110+ Brownish yellow (10YR 6/6) sand; single grain; loose.

Particle size distribution of Plainfield loamy sand.

	V.C.S.	C.S.	M.S.	F.S.	V.F.S.	C.Si.	M.Si.	F.Si.	Clay	Total
Ap	0.5	14.1	46.4	20.8	5.0	1.5	4.0	2.5	5.5	100.00
B2	0.9	12.1	42.0	22.8	6.6	1.5	4.0	1.5	4.5	100.00
B22	0.6	7.5	55.2	28.5	4.3	0	0.5	0.5	3.5	100.00
B3	4.2	12.1	53.7	24.1	3.9	0	0	0	2.0	100.00
C	1.8	6.9	34.8	40.1	5.9	0	0	0	1.5	100.00

PEDON: Near Neillsville, (similar to pedon of Mound System II) (Sec. 3.6.2 + 3.6.3).

LOCATION: Clark County Wisconsin: NE$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 10, T24N, R3W 10 meters west of the mound system and 15 meters north of the house (see map of area).

CODE: CAT 1

DATE OF DESCRIPTION: June 17, 1970 by J. Bouma, D. J. VanRooyen and W. Walker.

PARENT MATERIAL: Wind blown sandy deposits over weathered, stratified, sandstone bedrock. Surface of bedrock estimated to be at 2 m.

PHYSIOGRAPHY: Gently rolling low land.

DRAINAGE CLASS: Well drained.

SLOPE AND ASPECT: 2% northwest.

VEGETATIVE COVER: Soil covered 50% by new growth of grasses and weeds.

GROUNDWATER: Observed in profile pit at a depth of 145 cm below surface. (see cross section in Chapter 3.6.2).

CLASSIFICATION: Typic Haplorthod, coarse-loamy, mixed, frigid; Humbird sandy loam.

A1 0-5 — Black (10YR 1.7/1*)$^{+}$, sandy loam;apedal; very friable; clear and wavy boundary.

A2 5-11 — Dark brown (7.5YR 3/1) in the upper part of the horizon grading into brown (7.5YR 5/2) in the lower part, sandy loam; apedal; friable; clear and smooth boundary.

B21hir 11-15 — Yellowish red (5YR 4/6), sandy loam; apedal; friable; gradual and smooth boundary.

B31 20-28 — Yellowish brown (10YR 5/6), sandy loam; weak fine subangular blocky; slightly firm; diffuse and smooth boundary.

B32 28-38 Yellowish brown (10YR 5/4), sandy loam; weak fine subangular blocky; slightly firm; gradual and broken boundary.

IIC1 38-50 Pale olive (5Y 6/3), channery (30%) sandy loam; weak fine subangular blocky; slightly firm; gradual and smooth boundary.

IIIC2 >50 From 50 to 100 cm depth there are three distinct interstratified bands of:

White (5Y 8/2) sand, apedal, single grain; moderately cemented; brittle; abrupt smooth boundary.

Yellowish brown (10YR 5/4), sand; similar to white sand in other properties.

Olive gray (10Y 5/2)+, clay bands; apedal, composed of medium horizontal strata; very plastic, slightly sticky; many distinct medium strong brown (7.5YR 5/8) iron cutans along horizontal strata; abrupt and smooth boundary.

Below 100 cm there is coarse white sand (5Y 8/2), weakly cemented. Cementation increases with depth. Unweathered sandstone is estimated to occur at 2 m depth.

*Colors are moist unless otherwise stated.

+Color and notation from Japanese Standard Soil Color Chart.

REMARKS:

1) There are 20 cm of mixed sandy soil overburden material on top of the A1 horizon, resulting from construction.

2) Top horizons (down to IIC2) vary in texture in the pedon. Where the percent of sand increases with depth the profile development extends deeper into the pedon, with the result that the B3 (7.5YR 6/3) extends to the IIIC2 in places.

Particle size distribution of Humbird sandy loam (Chapter 3.6.2 and 3.6.3).

	V.C.S.	C.S.	M.S.	F.S.	V.F.S.	C.Si.	M.Si.	F.Si.	Clay	total
A1	0.6	9.7	26.1	14.6	18.0	8.7	11.5	4.5	7.0	100.00
A2	1.8	13.0	28.5	15.1	20.1	4.5	10.0	2.5	5.0	100.00
B21hir	2.2	11.9	21.5	12.7	16.2	4.0	8.5	6.0	17.0	100.00
B22hir	2.0	10.4	19.2	12.0	15.0	4.5	11.5	7.5	16.0	100.00
B3	1.8	9.6	22.2	16.7	22.0	4.5	7.5	6.0	10.5	100.00
IIIC(sand)	0.7	8.6	56.2	28.3	4.2	0	0	0	2.0	100.00
IIIC(clay)	0.7	2.0	3.2	3.6	9.5	4.0	14.0	12.0	51.0	100.00

Appendix 6.2. Additional soil physical data of previously studied pedons.

Additional soil samples were collected from pedons studied during the previous field season (Bouma et al., 1970). Physical analyses were made following procedures as described in Section 2.4 of this report. Results are reported for:

1. Oshkosh clay (Typic Eutrochrept), near Omro, Wisconsin. One virgin and one cultivated pedon were studied. (Fig. 6.2.1a and Fig. 6.2.1b).
2. Tama silt loam (Typic Argiudoll), near Platteville, Wisconsin. One virgin pedon (Fig. 6.2.2a) and one cultivated pedon (Fig. 6.2.2b) were studied. Bulk density data for both pedons are presented in Fig. 6.2.2c.
3. Plano silt loam (Typic Argiudoll); near Madison, Wisconsin. One cultivated pedon was studied (Fig. 6.2.3).

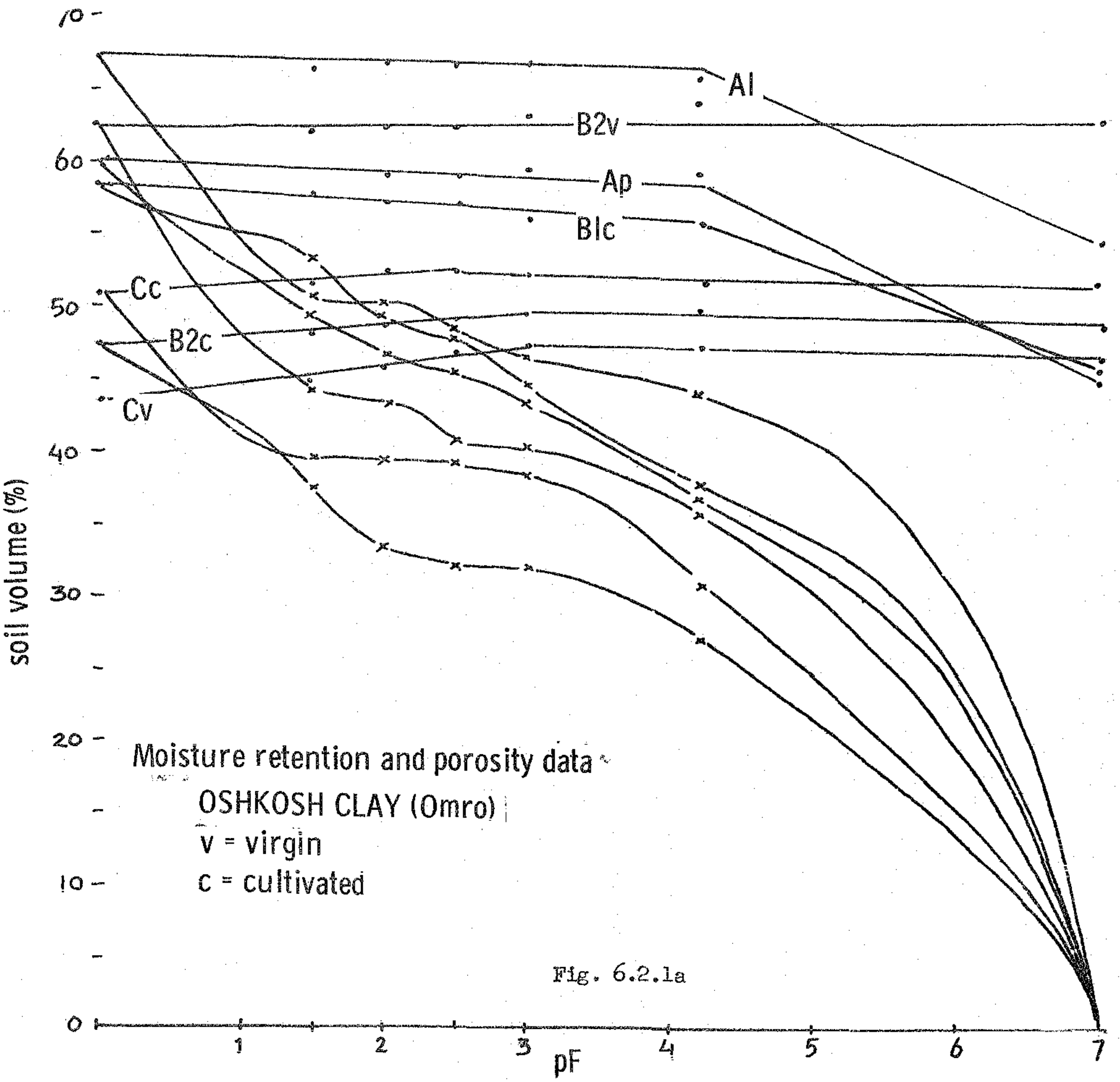

70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
pF
soil volume (%)
Al
B2v
Ap
Blc
Cc
B2c
Cv
Moisture retention and porosity data
OSHKOSH CLAY (Omro)
v = virgin
c = cultivated

Fig. 6.2.1a

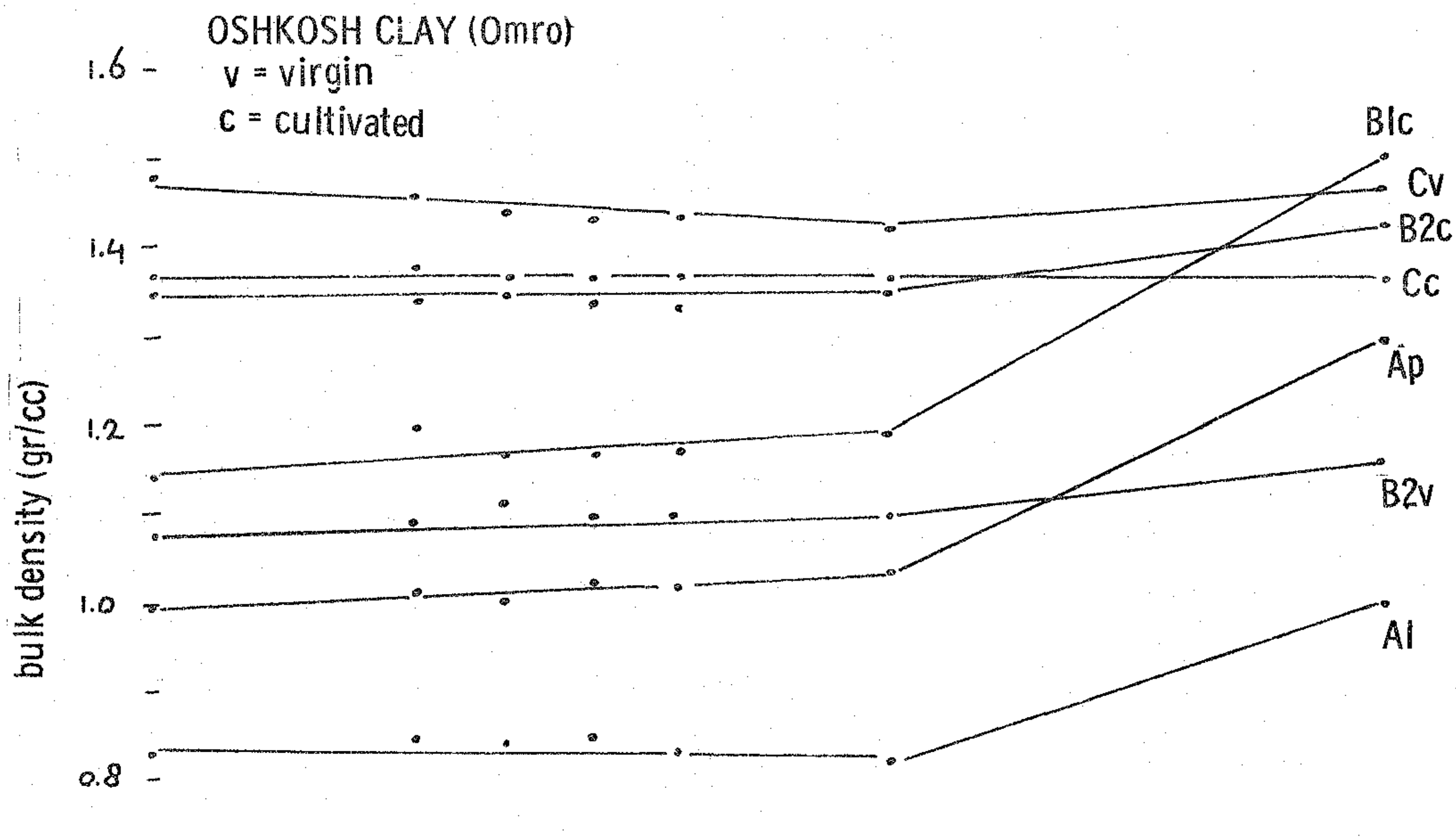
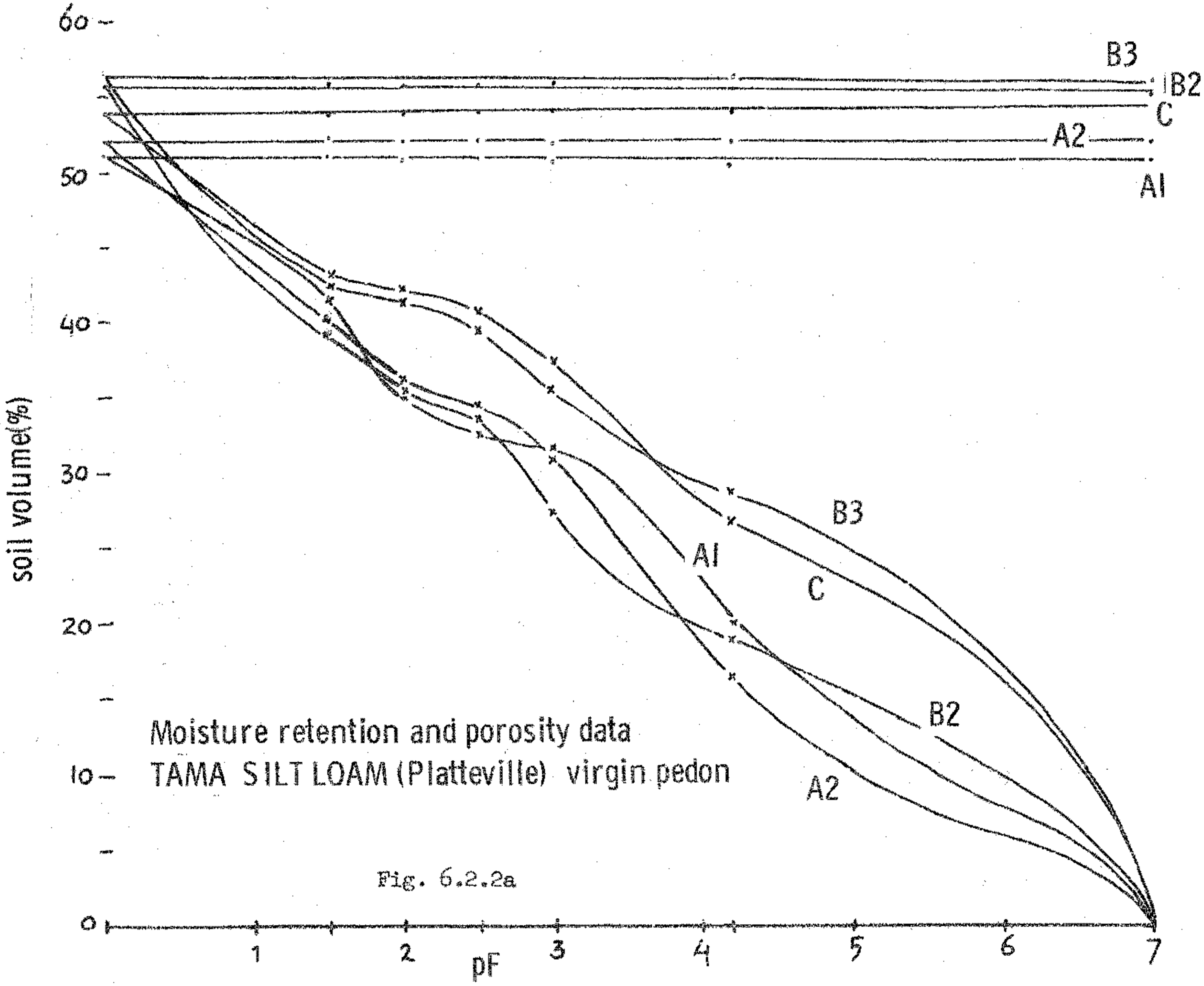

OSHKOSH CLAY (Omro)
v = virgin
c = cultivated
bulk density (gr/cc)
1.6
1.4
1.2
1.0
0.8
pF
1
2
3
4
5
6
7
Blc
Cv
B2c
Cc
Ap
B2v
Al

Fig. 6.2.1b



60
50
40
30
20
10
0
soil volume(%)
B3
B2
C
A2
AI
B3
AI
C
B2
A2
Moisture retention and porosity data
TAMA SILT LOAM (Platteville) virgin pedon
1
2
pF
3
4
5
6
7

Fig. 6.2.2a

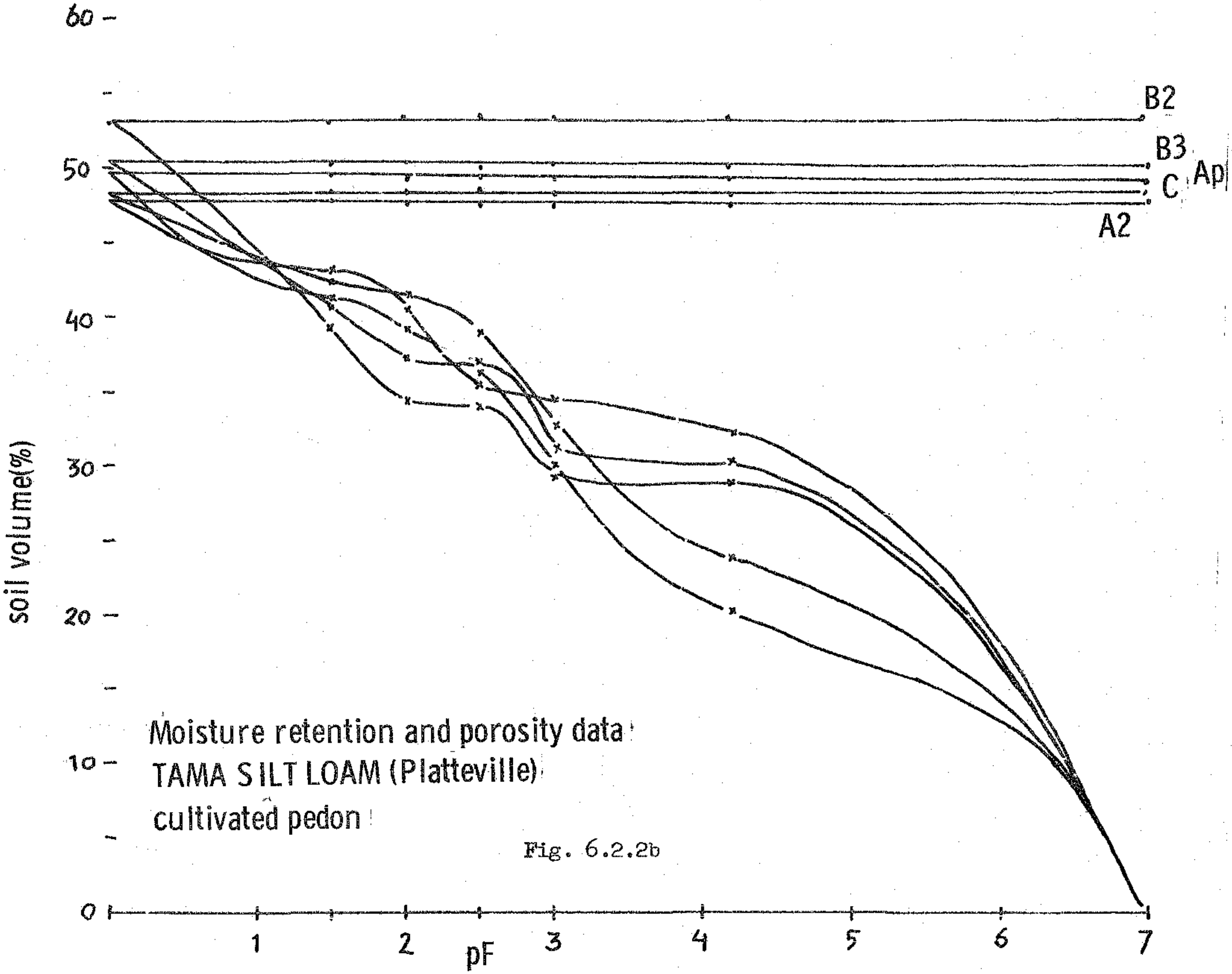

60
50
40
30
20
10
0
soil volume(%)
1
2
3
4
5
6
7
pF
B2
B3
Ap
C
A2
Moisture retention and porosity data
TAMA SILT LOAM (Platteville)
cultivated pedon

Fig. 6.2.2b

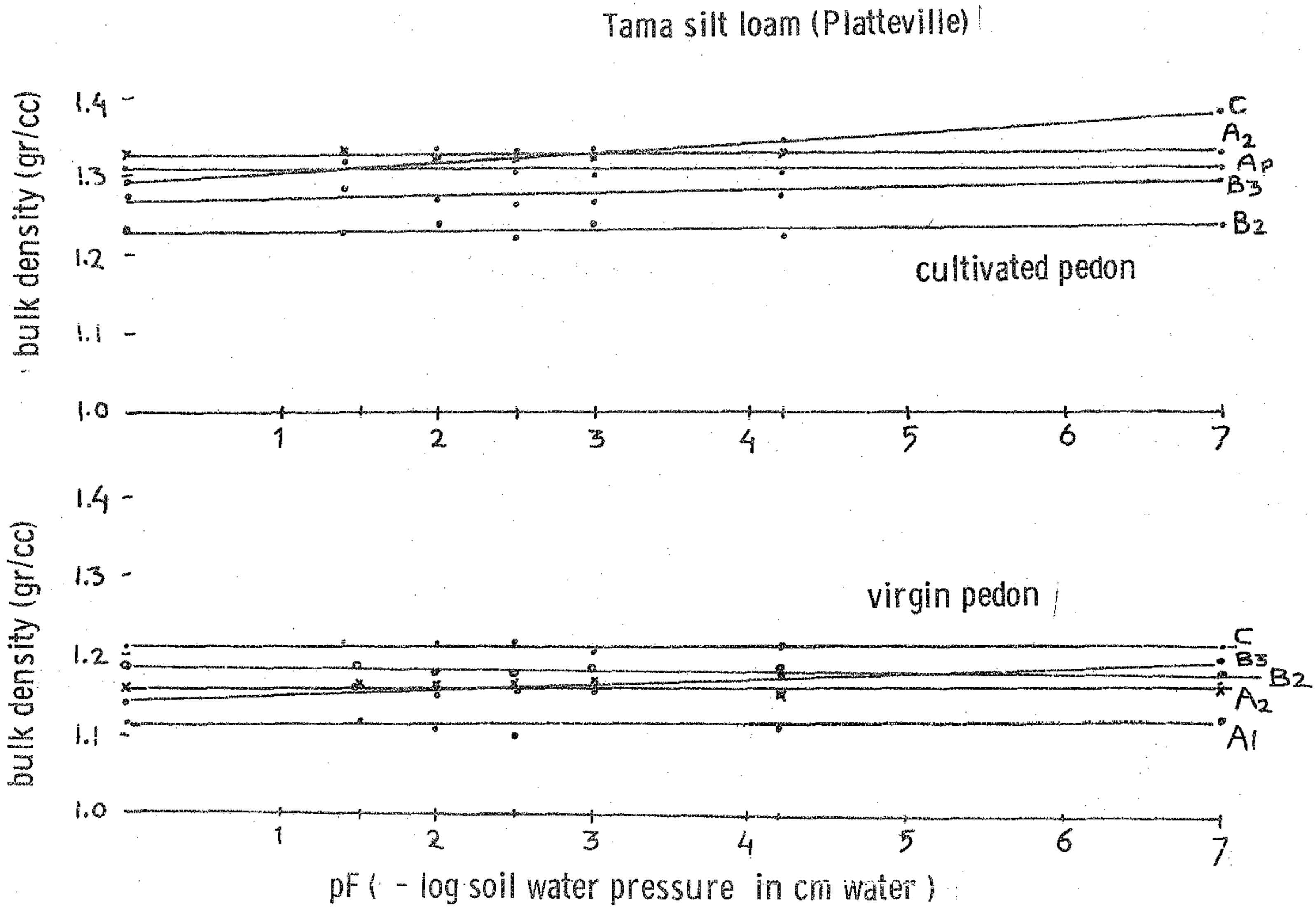

Tama silt loam (Platteville)
bulk density (gr/cc)
1.4
1.3
1.2
1.1
1.0
1
2
3
4
5
6
7
C
A2
Ap
B3
B2
cultivated pedon
bulk density (gr/cc)
1.4
1.3
1.2
1.1
1.0
virgin pedon
C
B3
B2
A2
A1
1
2
3
4
5
6
7
pF (- log soil water pressure in cm water)

Fig. 6.2.2c

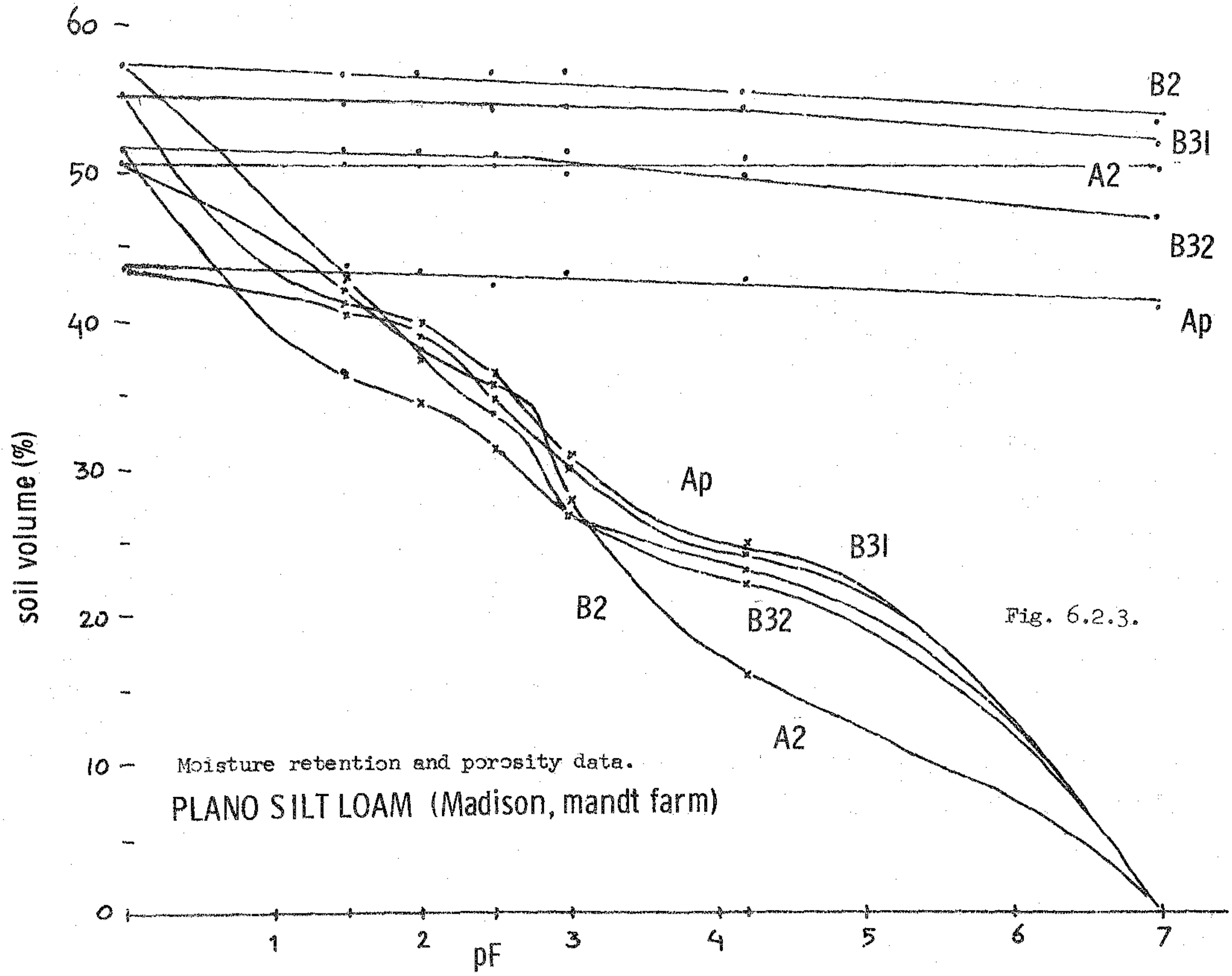

60
50
40
30
20
10
0
B2
B31
A2
B32
Ap
Ap
B31
B2
B32
A2
soil volume (%)
1
2
3
4
5
6
7
pF
Moisture retention and porosity data.
PLANO SILT LOAM (Madison, mandt farm)

Fig. 6.2.3.