SATURATED WATER PERMEABILITY OF SOILS AS RELATED TO AIR PERMEABILITY AT DIFFERENT MOISTURE TENSIONS

by

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SATURATED WATER PERMEABILITY OF SOILS AS RELATED TO AIR PERMEABILITY AT DIFFERENT MOISTURE TENSIONS

Introduction

The permeability of a porous medium is defined as the quantity of fluid of unit viscosity flowing per unit time under a unit pressure gradient through a unit cross-sectional area of a unit length. The permeability of a porous medium has been used to evaluate some of the physical characteristics of the medium. A measurement of the permeability has many assets, since it depends upon the porosity, degree of aggregation, grain size, their distribution, and shape factor for the grains. A measurement of permeability should yield a value that may be used as an index in evaluating such characters of a soil as erodability, drainability, and aeration capacity as well as the water and air permeability.

Soil scientists and drainage engineers are concerned with making permeability measurements in the field. The field methods available depend on complete saturation of the medium. In many instances, however, it would be advantageous to make permeability determinations when the soil is not completely saturated. Such is the case for instance when permeability measurements are needed for irrigation developments in areas where no water table is present.

Both theory and early research suggest the possibility of using air as a fluid instead of water in measuring permeability if the medium during the measurement does not change. In addition to making the permeability determination independent of the presence of the water table, air has the following advantages: (1) it eliminates the effect of entrapped air in the medium. (2) It eliminated the possibility of plugging of the medium by foreign matter contained in the fluid. (3) It does not disintegrate the structure of the medium as readily as a liquid and (4) it does not require as high a differential force as liquid to force it through the medium.

In order to use air permeability as a means for estimating the saturated water permeability, the relationship between saturated water permeability of soils and air permeability at different moisture tensions must be established. At the present time no method is available to deduce saturated water permeability from a measurement of air permeability at certain moisture tensions.

The objectives of this study were to establish the relationship between saturated water permeability and air permeability of disturbed and core soil samples. The necessary equipment was developed and constructed for obtaining such information.

LITERATURE REVIEW

The importance of air permeability as a physical characteristic of soils was recognized as early as 1879, by Renk, Ammon, and Wollny (1, pp. 219). These investigators showed that the permeability of porous media is completely independent of the nature of the fluid, if a physical change does not occur in the medium. They also showed that air permeability decreased with increasing moisture content, and increased with increasing amount and size of the soil pores.

By using beads and sand as media Green and Ampt (4, pp. 1-26) found that permeability was the same when either air or water was used, (see Table I).

Table I

Permeability (microns squared) of glass beads using different fluids as reported by Green and Ampt (4, pp. 1-26)

Diameter of Beads (mm.)	% Pore Space	Permeability of air (μ^2)	Permeability of water (μ^2)
0.938	0.36	4.96	4.70
0.709	0.37	3.30	3.33
0.497	0.36	1.53	1.52
0.319	0.36	0.62	0.61
0.319	0.37	0.69	0.67
0.250	0.37	0.37	0.37

A similar correlation was obtained when sand was used as a medium instead of glass beads. Also, Musakt (6, p.763) presented data showing the same effect using sand and sandstone as media.

Green and Ampt (3, pp.1-24) have observed that the air permeability of dry soils was higher than the saturated water permeability. Furthermore, it was indicated that as the colloidal material increased in the soil, the saturated water permeability values decreased more than air permeability values. From these results, it was expected that the air:water permeability ratio should be 1 if sand was used as a medium, and that the ratio should be expected to increase as the magnitude of the colloidal materials increased. Reeve (8, pp.324-329) used the air:water permeability ratio as a tool for measuring the structure stability of soils. The measurement being made first with air, and then with water. The change in permeability was attributed to the instability of the soil to the wetting action of the water. The air:water permeability ratio was shown to be correlated with both the exchangeable-sodium-percentage and clay content of soils.

Corey (2, pp. 7-10) has measured the simultaneous flow of air and water under the same pressure gradient. When the air permeability values were plotted against the percent moisture content in the soil, it was found that, when the sand was saturated, the air permeability was zero. Then, by decreasing the moisture content, the air permeability increased. Renk (7, pp. 339-347) showed the same relation, and attributed that behavior to an increase in the percent pore space upon drying the soil. Syekoff and Botset (9, p. 325) found that, by plotting the relative permeability values against the soil moisture content, a S-shape curve invariably was obtained. This conclusion was again related to the manner in which the large pore spaces were behaving with drying.

OBJECTIVES OF THE STUDY

The general objective was to evaluate air permeability as a means of estimating saturated water permeability in the field. The specific objectives were:

1. To compare air permeability at different moisture tensions and the saturated water permeability under laboratory conditions.
2. To measure the air porosity at different moisture tensions and relate to moisture tension and air permeability.
3. To relate air permeability and water permeability under field conditions if the correlations in the laboratory phase justify further study.

APPARATUS AND PROCEDURE

The above mentioned objectives were accomplished by first using disturbed soil samples with a range in texture to get variations in permeabilities. The soil textures used were coarse sand, fine sand, loamy sand, sandy loam, sandy clay loam and clay loam. Saturated water permeability of the disturbed samples was first measured. A range of tensions was exerted on each sample gradually. For each tension the percent pore space and air permeability were measured. The saturated water permeability and the air permeability of the disturbed soil samples were obtained under constant temperature and humidity. Since the action of water on soil is such that saturated water permeability usually decreased with time, only the first values were recorded. Core samples of soils similar in their range of texture to the disturbed samples, were taken from the field at two levels of soil moisture content. Tensiometers were installed in these different fields after the sites were selected for sampling. The tensiometers aided in estimating the soil moisture tension. One set of core samples was taken from these soils when the moisture was around 100 cm. of water tension, and the other set was taken when the soils were drier. The tensions specifically were recorded for each site in Table 2 in the appendix. Air permeability of these cores was measured immediately after they were brought from the field, and followed by measuring their saturated water permeability.

The apparatus and procedures are presented in detail for the disturbed and core samples.

Procedure for Disturbed Soil Samples.

About 450 cc. of soil were required for each sample. The air-dried samples were passed through 2 mm. sieve and each sample was thoroughly mixed. The uniformity of packing of the soil sample in the container is not as important in this study as in many other cases since the saturated water permeability and air permeability were measured on the same sample. Therefore any nonuniformities will show in both measurements.

The soil container into which the soil was packed for both air and water permeability determinations, as shown in Figure 1, consisted of a 650 ml. sintered glass funnel. A 0.5 cm. hole was opened in the wall of the funnel about 2 cm. from the top, and an outflow tube made of glass was connected to it. A 3-way stopcock was attached on one side to the bottom of the sintered glass funnel and on the other side to burette B. A flexible rubber tube filled with mercury was connected to burette A on one end and to burette B on the other end. The lower part of the funnel below the sintered glass filter and burette B was filled with water down to the mercury level.

The disturbed soil sample was added to the funnel in two parts. The first part was packed in the container to a height of 2.8 cm. above the sintered glass filter. This distance was determined by an electrical analogue which will be discussed in a later section. Part of the soil was put first in the container in a single motion to a height of 2.8 cm. from the sintered glass filter. A plastic cylinder of 7 cm. in diameter was used as an inlet and was located centrally

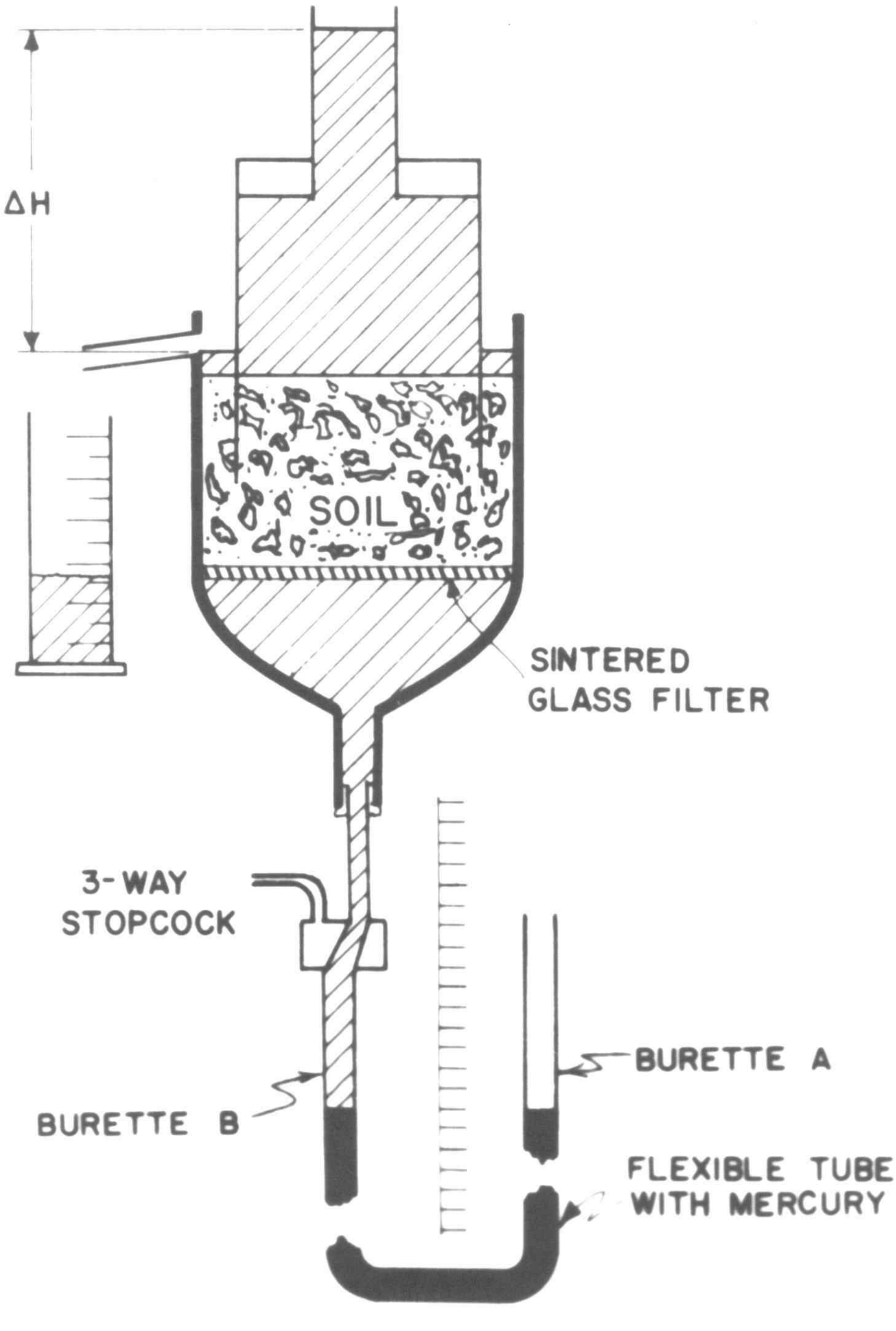

Figure 1. Schematic diagram of the apparatus used to measure saturated water permeability of disturbed soil samples.

in the funnel. The rest of the 450 cc. of the soil sample was added to the funnel and filled it up to the outlet hole. The sample was smoothed, and tamped with a piede of wood. The soil surface area within the cylinder was approximately equal to the soil surface outside of the cylinder.

Saturated water permeability: The effect of entrapped air upon the saturated water permeability measurement was eliminated, or at least minimized by initial displacement of the air in the sample with CO_2. The soil samples were wetted from underneath; by raising burette A upward, the mercury level in burette B raised up pushing the water through the sintered glass filter and wetting the sample. The sample was wetted in steps, since there was not enough water in burette B to saturate the sample. Everytime the water in burette B was consumed, more water was added through the three-way stopcock to replenish the used water. This procedure was repeated until the entire sample was completely saturated. Following the wetting step, the stopcock was turned off, and water was poured through the inlet. Extra caution was taken in pouring the water to prevent disturbance of the soil. A constant head Δh was maintained in the inlet, the overflow of water was collected and the time interval was recorded. The following form of Darcy's law was used to calculate the saturated water permeability:

$$q = \frac{k_w \cdot A \cdot \Delta h}{\mu} \qquad (1)$$

where

q = the quantity of water flowing per unit time (cc/sec.)

k_w = the saturated water permeability (cm.^{2})

A = is the effective cross-sectional area divided by the effective length of the flow (cm.)

Δh = the hydraulic head gradient (dyne/cm.^{2})

μ = the viscosity of water at the temperature of measurement (poise, i.e., dyne-sec./cm^2).

Air permeability: Following the saturated water permeability measurement, the excess water above the soil was drained out leaving the soil completely saturated. Then by applying increased increments of suction to the soil, the air permeability and pore space at different tensions were obtained. The apparatus shown in Figure 1 was slightly modified for the air permeability and porosity measurements and presented in Figure 2. Compressed air was admitted to a pressure regulating cylinder. The pressure regulator was a 1000 ml. graduated cylinder filled with water and closed at the top with a rubber stopper. Two holes were drilled in the stopper, one was used as a bleeding source and a T-shaped glass tube was fitted in the other. The perpendicular part of the T went inside the cylinder while the right branch was connected to the air source, and the left one went to a flow meter. The flow meter was made by the American Meter Company, model no. 366. The air passed from the meter to the inlet cylinder in the apparatus which was used for the saturated water permeability determinations. A simple water manometer was attached to the stopper on the top of the inlet cylinder as shown in Figure 2 to measure the pressure drop of the air across the sample. In order to create a suction on the soil sample in the funnel, burette A was lowered. This action created a suction equal to the difference in the mercury

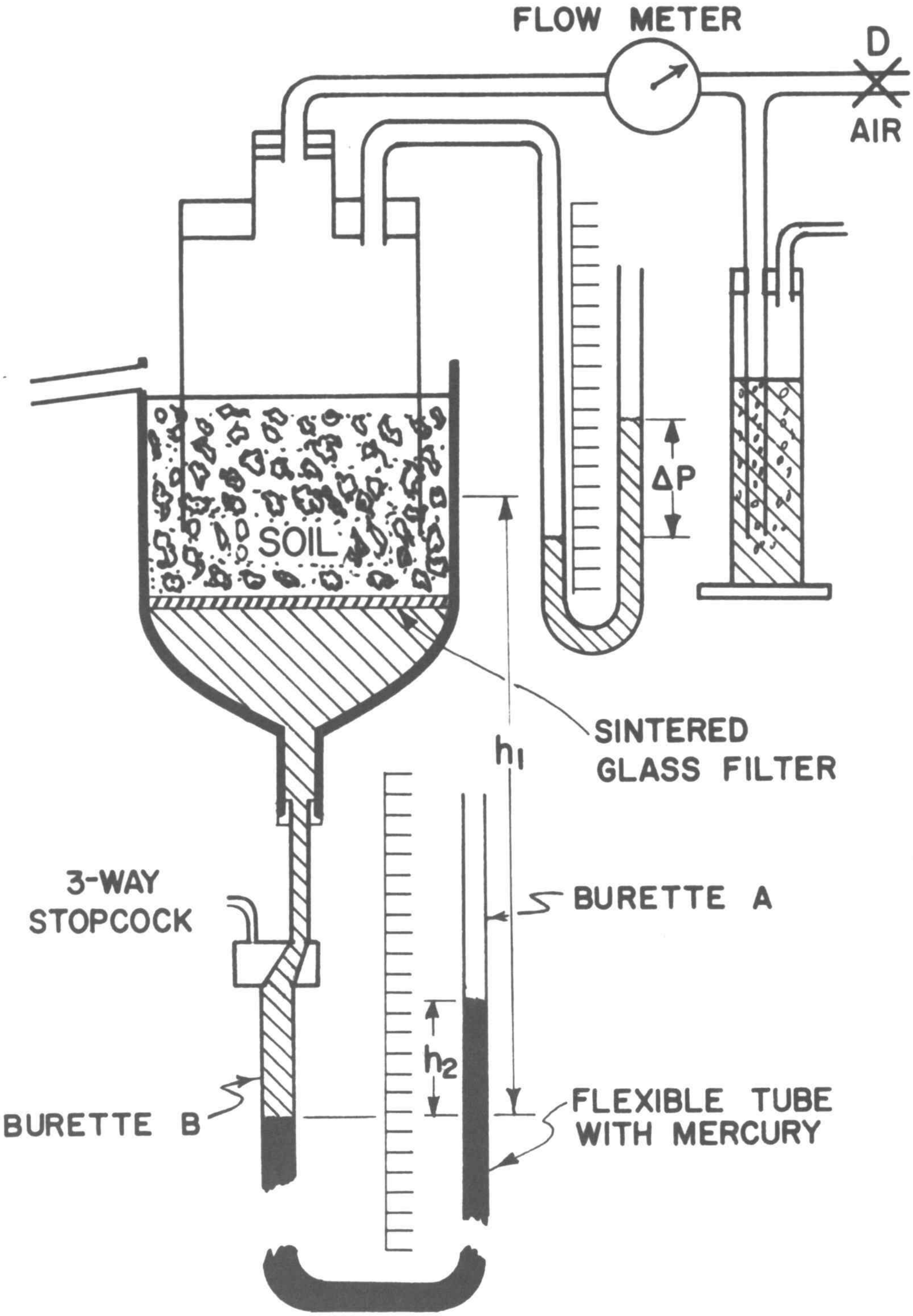

Figure 2. Schematic diagram of the apparatus used to measure air permeability of disturbed soil samples at different moisture tensions.

level between burette A and B, as indicated by h_2 in the diagram, plus the water column from the mercury-water interface in burette B up to the middle height of the soil sample, as indicated by h_1 in the diagram. After equilibrium was reached, the amount of water which was drained from the soil sample due to the applied suction was estimated by the difference in the mercury level in burette B, before and after lowering burette A. The volume of the water which was drained from the sample was used as an estimate for the pore space in the sample.

For measuring the air permeability at each tension, the compressed air valve D was turned on. The volume of air which passed through the sample per unit time was recorded. The pressure difference of the air across the sample in dynes/cm^2 was recorded by the aid of the manometer, as indicated by ΔP in the diagram. The permeability of the soil to the air was calculated using the following form of Darcy's law:

$$q = \frac{k_a \cdot A \cdot \Delta P}{\mu} \qquad (2)$$

where

k_a = the air permeability (cm^2)

The other terms were defined in the text following equation (1).

The A factor was determined by an electrical analogue. For the electrical case with the same geometry as that of the water and air cases:

$$I = \sigma \cdot A \cdot \Delta V \qquad (3)$$

where

$I =$ the electrical current (amperes)

$\sigma =$ the electrical conductivity of the medium (mhos/cm.)

$A =$ constant value which is identical to that in equation (1) and (2) (cm.)

$\Delta V =$ the voltage drop across the sample (volts)

Equation (3) can also be written as:

$$A = \frac{1}{\sigma \cdot R}$$

where

$$R = \frac{\Delta V}{I}$$

The electrical analogue which was used for determining A, is shown in Figure 3. Potassium chloride solution of 0.001 N was used as a conduction medium. Two small pieces of copper, used as electrodes, were soldered to two wires and then cemented to a plastic disc which has the same I.D. as that of the funnel. A plastic tube of the same diameter and thickness as that which was used as an inlet tube in Figure 1 and 2, was cemented in the center to the plastic disc.

The funnel was filled with potassium choloride solution of a known conductivity, then the plastic disc was placed on the surface. In the beginning of the experiment, the plastic cylinder was almost touching the filter. The resistance between electrodes A and B was registered twice, first with potassium choloride solution underneath the filter, and second when the solution was drained out. After the

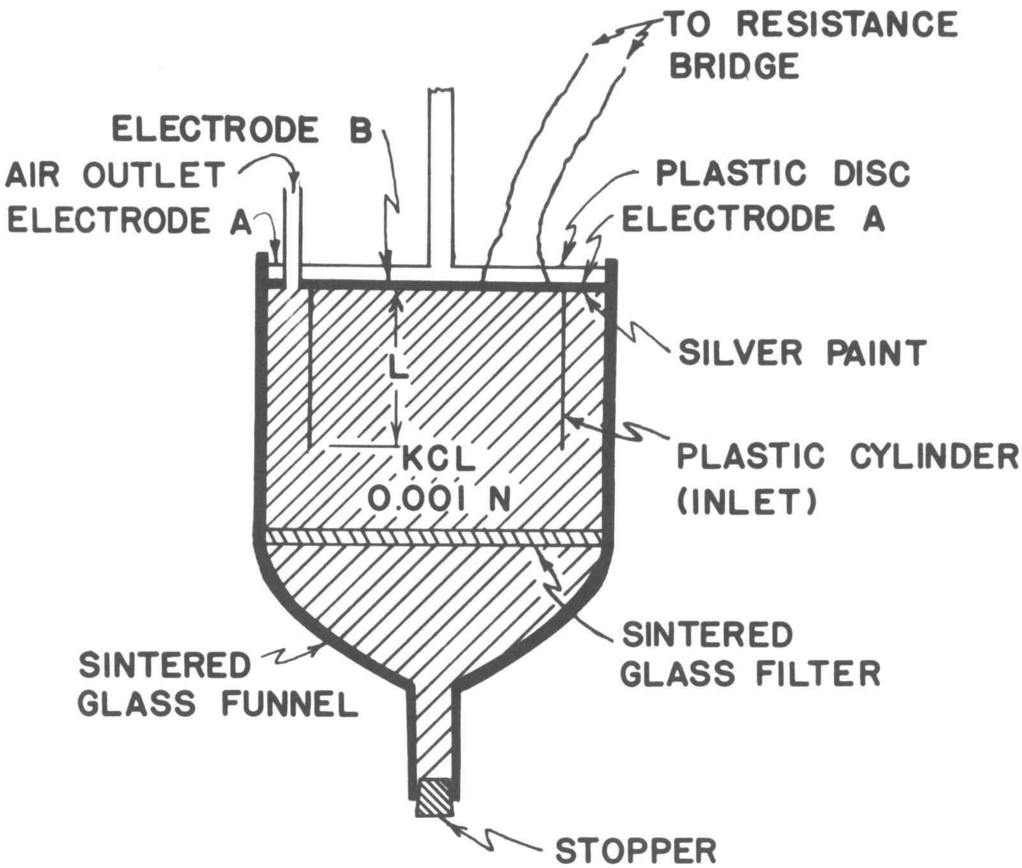

Figure 3. Schematic diagram of the electrical analogue.

two resistance readings were recorded, the end of the plastic cylinder was shortened slightly and another set of readings was recorded. This process was repeated several times until there was no change in the resistance with or without potassium chloride solution under the filter which indicated that there was not a flow of electricity through the filter. The length of the plastic cylinder then was found to be 2.8 cm. and was considered as the desirable depth of the inlet.

For calculating the A factor, equation (4) was used since the inlet depth was just measured and all the other terms except A were known.

Procedure for Core Samples:

Core samples were taken from soils with textures of fine sand, sandy loam, sandy clay loam, and clay loam. After a site was selected, a tensiometer was placed at the depth to be sampled. When the tensiometer read 100 cm. of water tension or more, core samples were taken. The Uhland core sample, which takes cores 3 inches high and 3 inches in diameter, was used. Two or three cores were taken from each site.

Air permeability of these cores was measured, followed by measuring the saturated water permeability after flushing the samples with carbon dioxide.

A schematic diagram of the apparatus which was used for measuring the air and the water permeabilities of the core samples, is shown in Figure 4. The base of the apparatus was composed of an

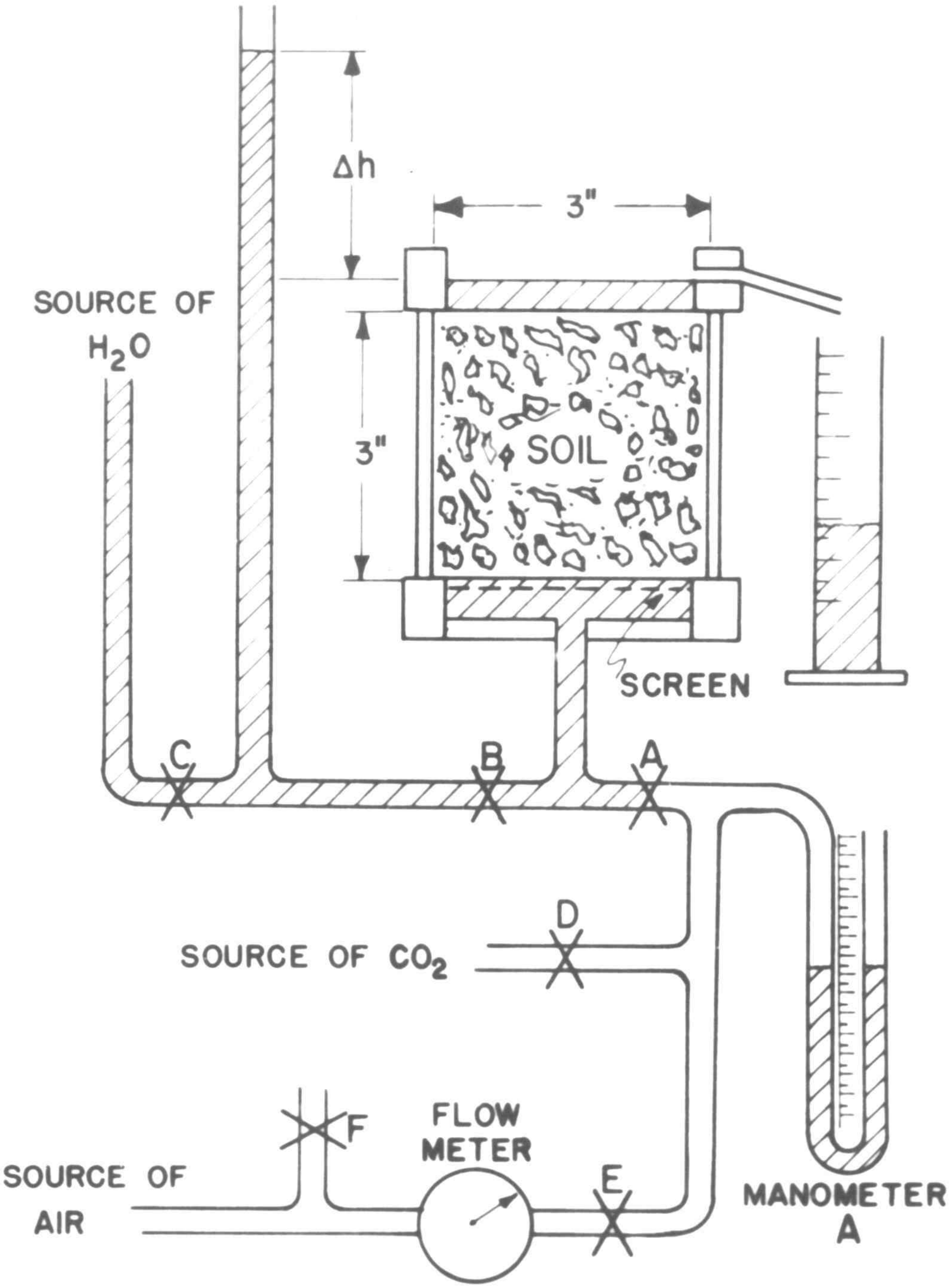

Figure 4. Schematic diagram of the apparatus which was used to measure saturated water permeability and air permeability of core samples.

aluminum sheet and soldered to it was a cylinder 1 inch long and 3 inches in diameter. Centrally located in the cylinder was an inlet hole for the fluids. A screen was held by a brass cylinder, to a height equal to that of the aluminum cylinder. The core containers were placed upon the base, and separated by a rubber washer. Another cylinder was placed on top of the core container and again separated by a rubber washer. The top cylinder had a side outlet which provided an overflow for the water passing through the soil. The entire unit was clamped together by two bolts.

In order to measure the air permeability, clamp B was shut off and A was turned on. The quantity of air which passed through the sample per unit time was recorded by the air flow meter and a stop watch. The form of Darcy's law which was used to calculate the air permeability is similar to that in equation (2) except for the A factor. The A factor here is equal to $\frac{A'}{L}$. A' is the cross section of the cores in $cm.^2$ and L is the length of the cores in cm.

Before measuring the saturated water permeability, the effect of entrapped air upon the measurement was first minimized by initial displacement of the air in the cores with carbon dioxide. A constant head equal to Δh was applied on the core sample and the quantity of water which passed through the sample per unit time was measured. The saturated water permeability was calculated by using the same form of Darcy's law as that which was used for measuring the air permeability, except that Δh was substituted for ΔP.

RESULTS

Data are presented for air and saturated water permeabilities on both disturbed and core samples. Permeability may be expressed in square centimeters ($cm.^2$), but for soils this necessitates the use of small numbers. The square micron (μ^2) is a unit which has been found to be convenient for use with soils and is used in this thesis.

Results for Disturbed Samples:

For the disturbed samples, the air permeability values were plotted against the moisture tensions for each soil separately and are presented in figures 5, 6, 7, 8, 9 and 10. Also on these graphs the values of the saturated water permeability are marked for comparison. The actual data were presented in Table 1 in the appendix. It can be noticed very distinctly in Figure 1, where coarse sand was used as a medium, that the air permeability increased very sharply between ten and twenty-five cm. of water tension. Then air permeability increased slowly as tension increased up to 100 cm. of water tension. Beyond 100 cm. of water tension the air permeability stayed constant as tension increased. The fast change in permeability with the narrow range of tension, may be related to the fact that most of the macropore spaces were drained in that range of moisture tension. Since permeability is mainly a function of the macropore spaces, one should expect very little change in their permeability after the macropore spaces drain out, as indicated by the shape of the curves.

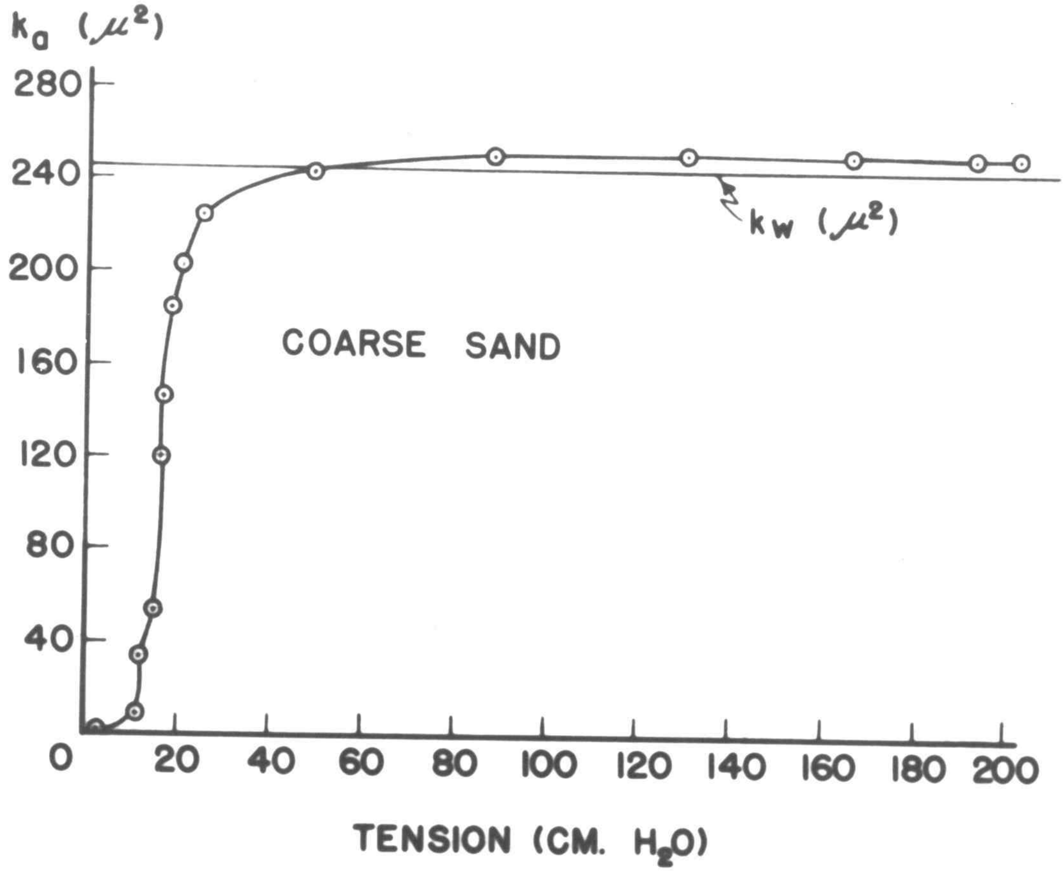

Figure 5. Measured values of air permeability of disturbed coarse sand versus soil moisture tension.

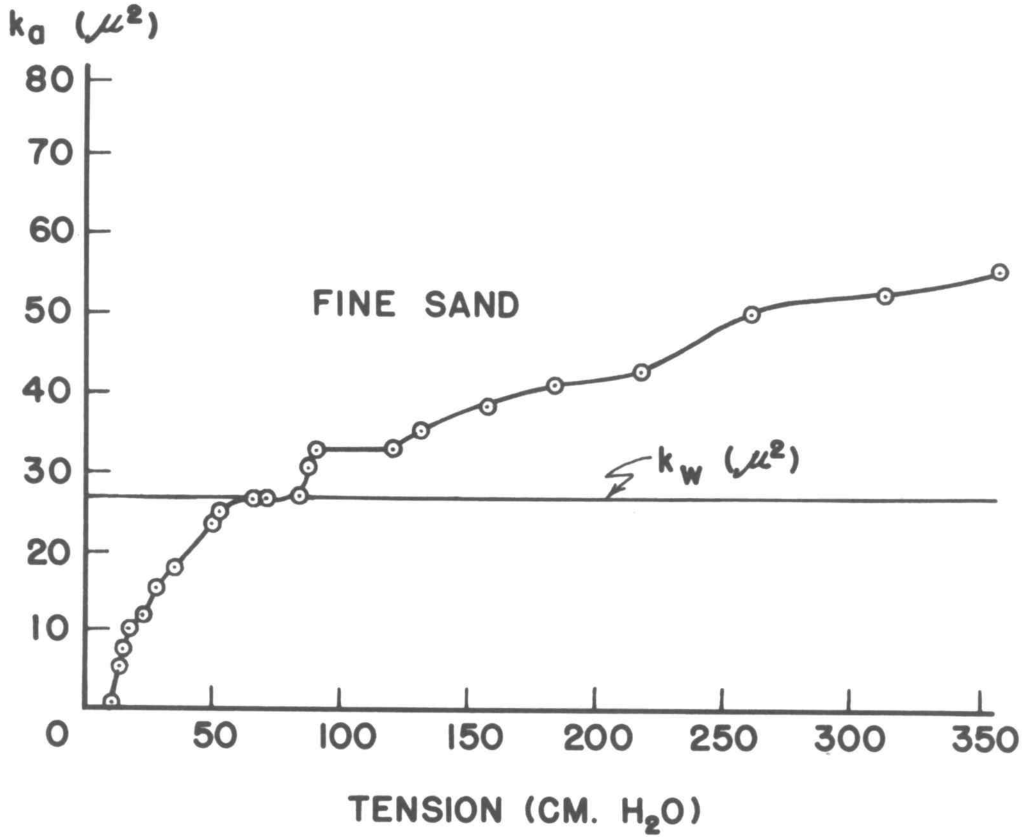

Figure 6. Measured values of air permeability of disturbed fine sand versus soil moisture tension.

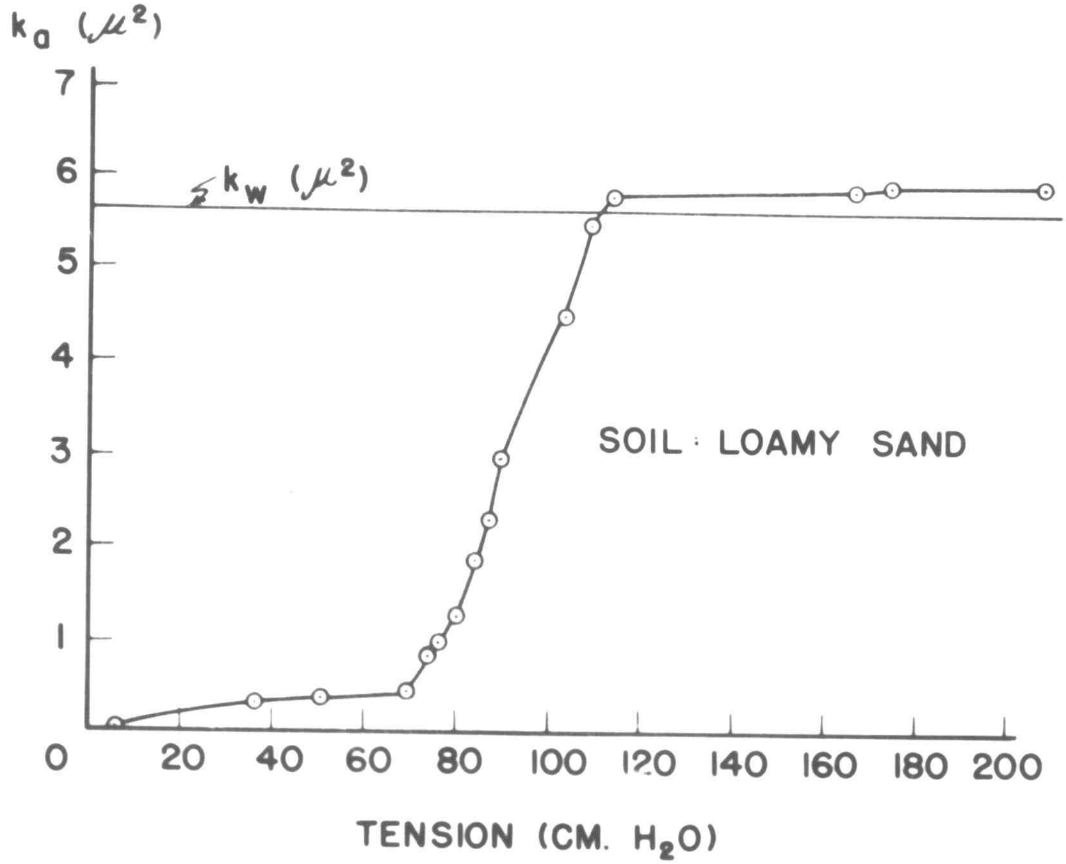

Figure 7. Measured values of air permeability of disturbed loamy sand soil versus soil moisture tension.

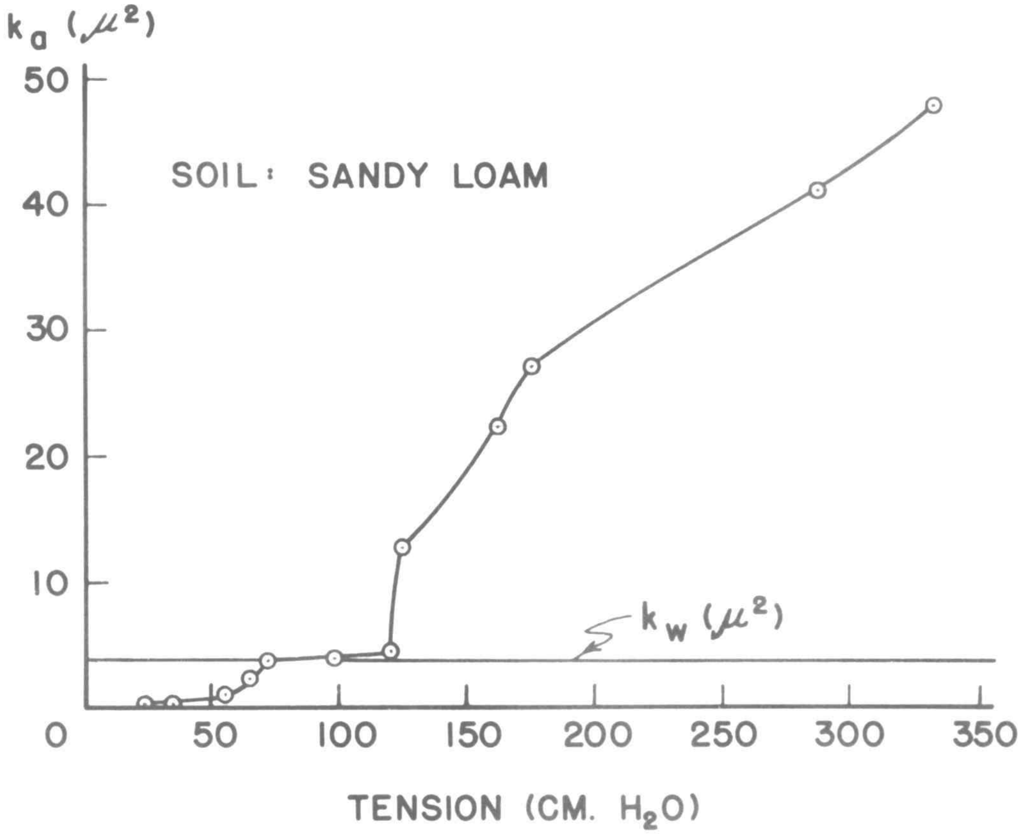

Figure 8. Measured values of air permeability of disturbed sandy loam soil versus soil moisture tension.

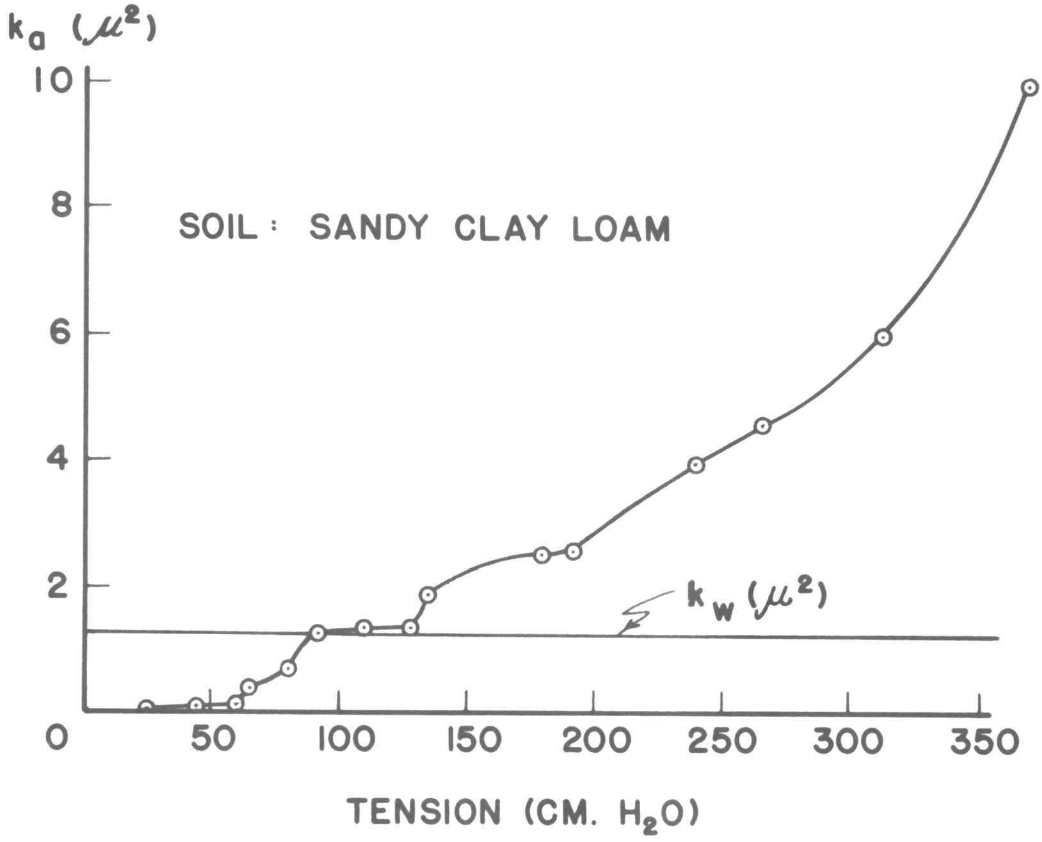

Figure 9. Measured values of air permeability of disturbed sandy clay loam soil versus soil moisture tension.

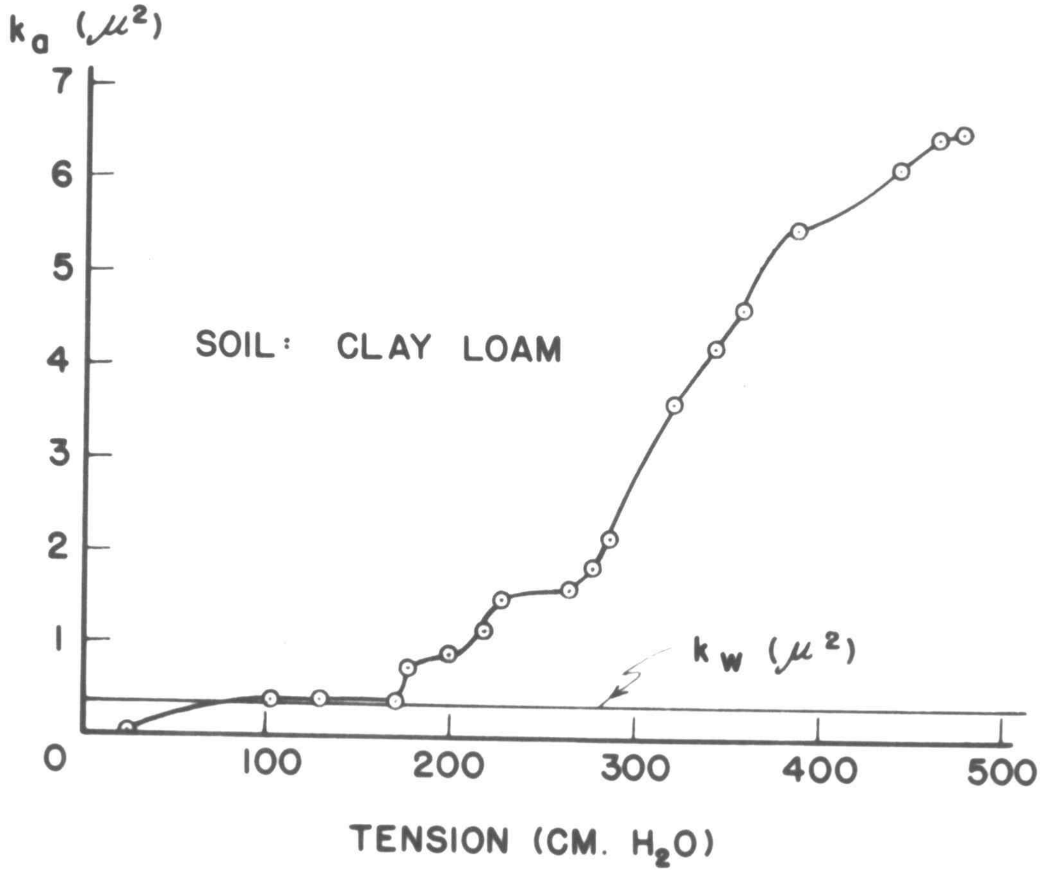

Figure 10. Measured values of air permeability of disturbed clay loam soil versus soil moisture tension.

As the clay content increased in the samples, a greater tension was required before a noticeable increase in air permeability was observed. Apparently the air permeability tended to level off around 100 cm. of water tension for all the samples. Since permeability is mainly a function of the macropore spaces, the observation just mentioned could mean only, that most of the macropores for all the examined soils drained around 100 cm. of water tension. It was noticed especially in the heavy textured soils, that cracks appeared as the tension increased above 100 cm. of water tension. Therefore, the change in permeability in the heavy textured soils after it levelled off around 100 cm. of water tension, is believed to be due to the crack formation. Furthermore, the air permeabilities at 100 cm. of water tension, approached the saturated water permeability of the samples.

Air permeability of the disturbed soil samples at 100 cm. of water tension were plotted against the saturated water permeability and are presented in Figure 11. The bisector was drawn in Figure 11, and it appreared to be the best fit line for the data. This correlation means that air permeability at 100 cm. of water tension is a good estimate for the saturated water permeability of the sample.

The percent pore spaces for the different soils were plotted separately against tensions and are presented in Figures 12-17. One can notice that the sharp increase in percent pore space with respect to tension for all the soils, occurred before 100 cm. of water tension. As tension increased above 100 cm. of water, there was a comparatively slow change in percent pore space.

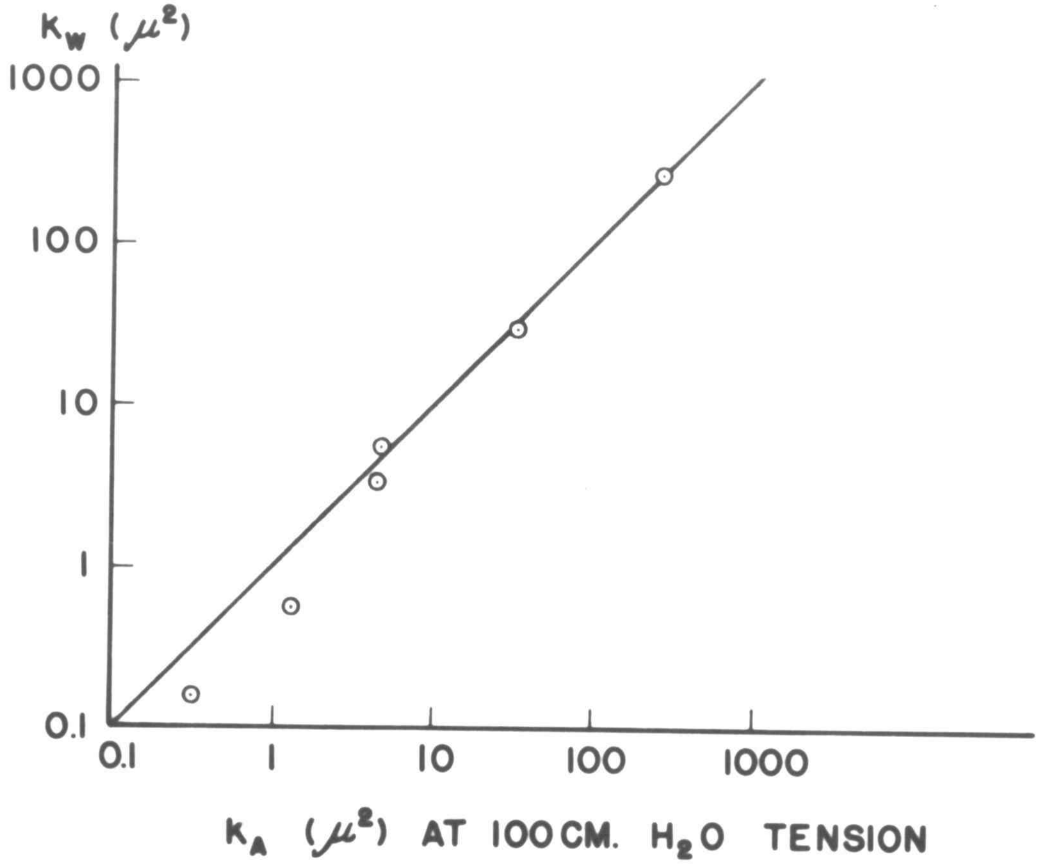

Figure 11. Air permeability of disturbed soil samples at 100 cm. of water tension versus saturated water permeability.

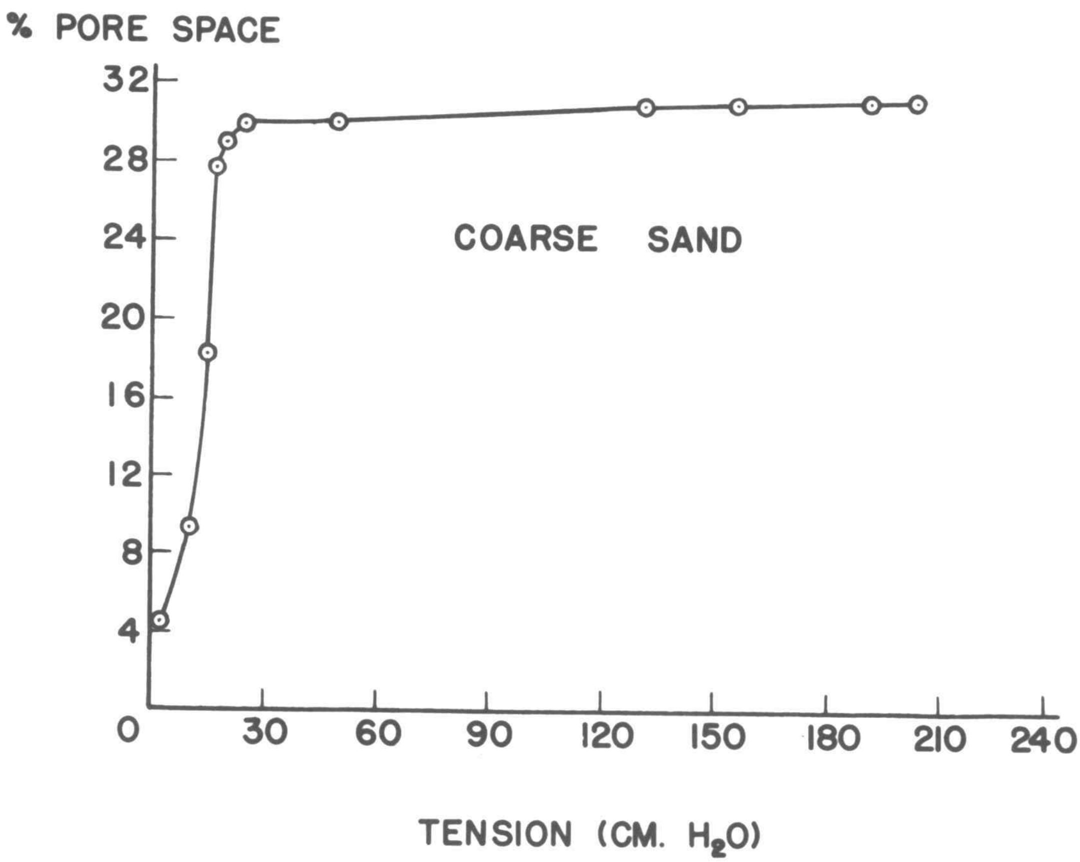

Figure 12. Percent pore space of disturbed coarse sand versus tension.

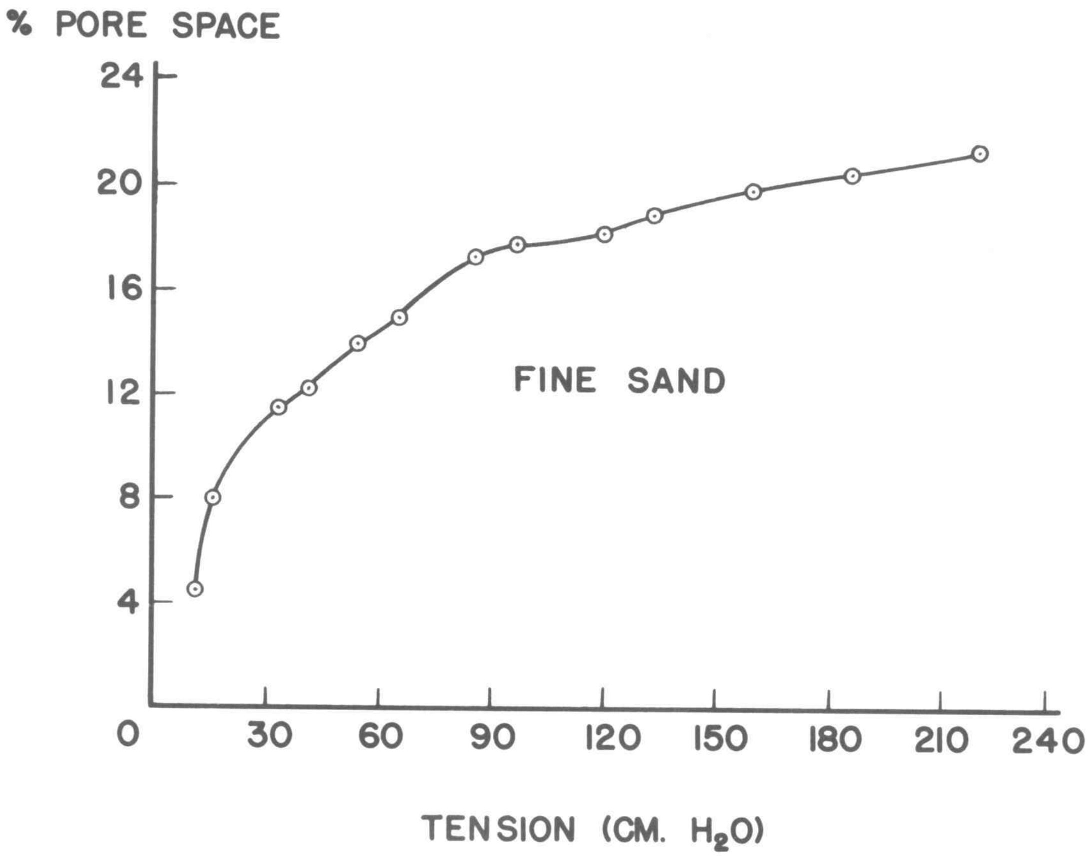

Figure 13. Percent pore space of disturbed fine sand versus tension.

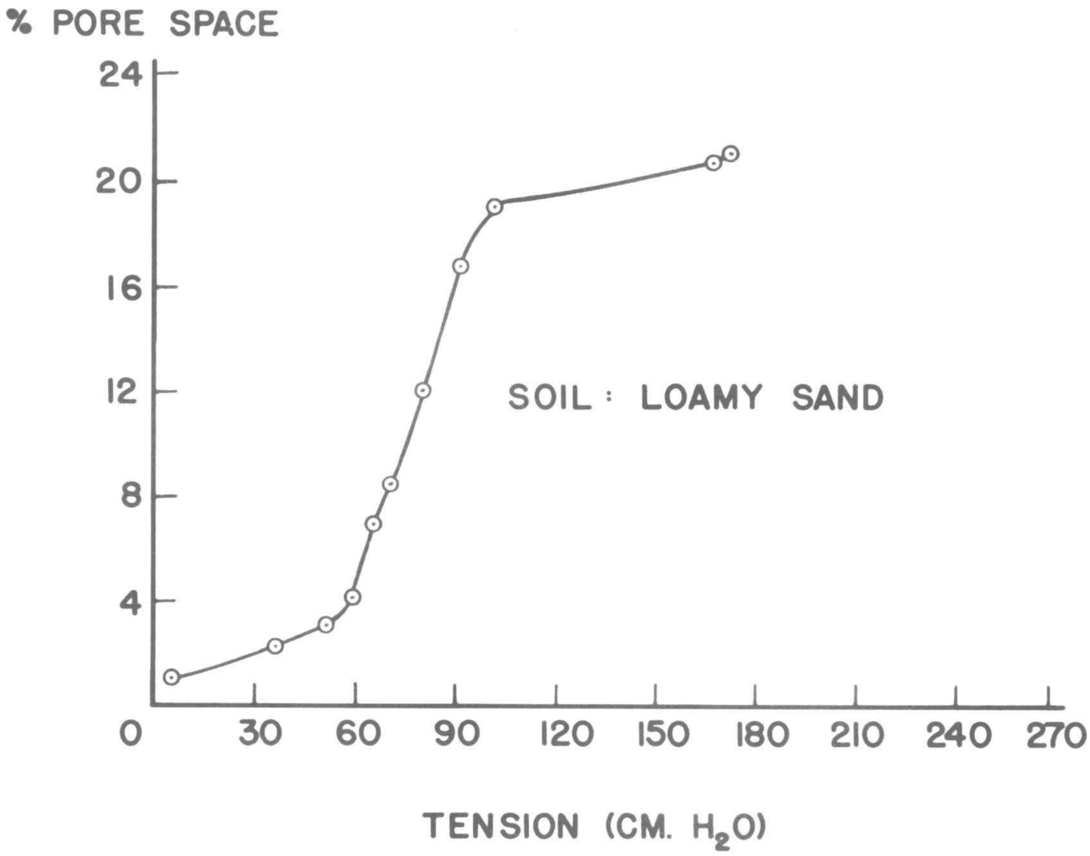

Figure 14. Percent pore space of disturbed loamy sand soil versus tension.

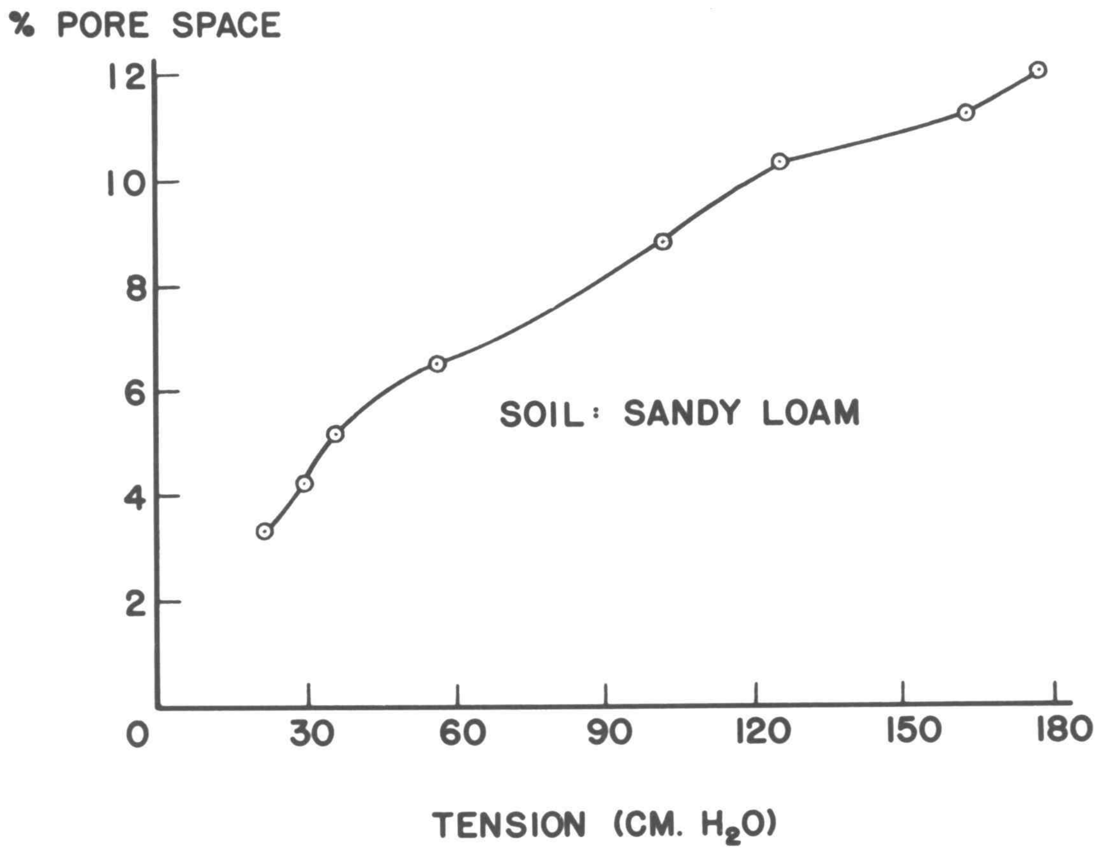

Figure 15. Percent pore space of disturbed sandy loam soil versus tension.

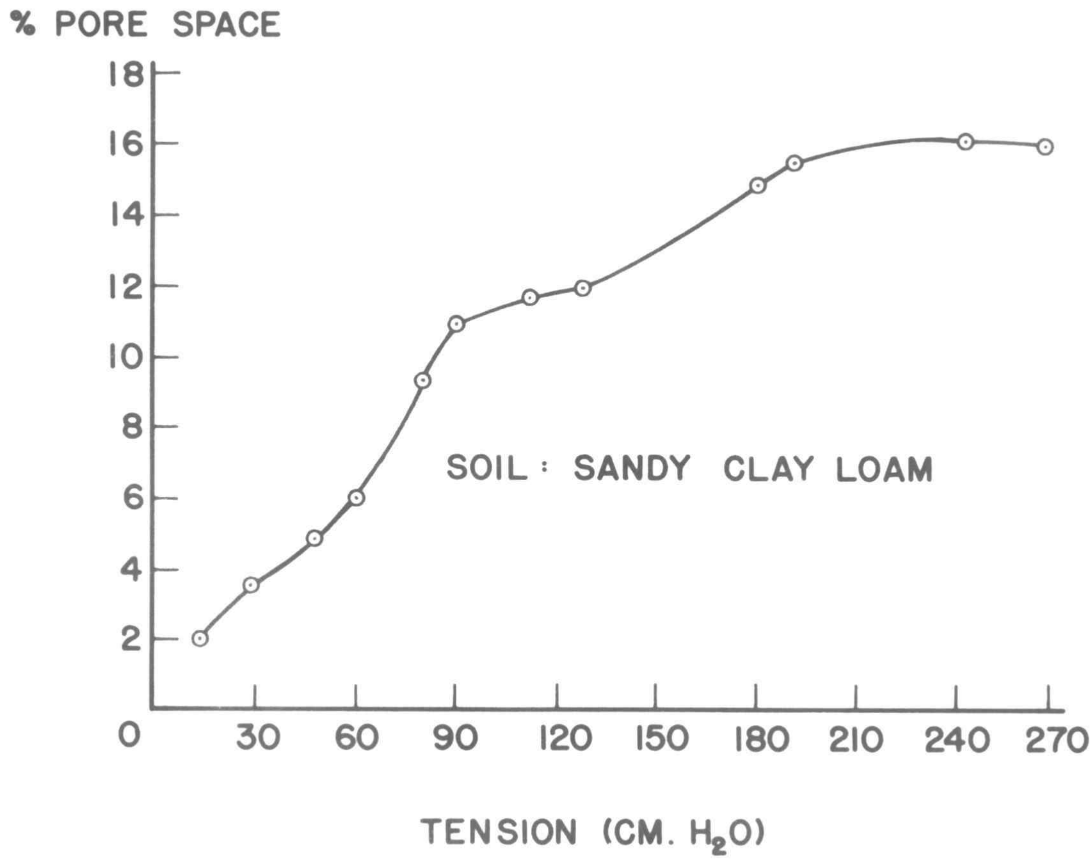

Figure 16. Percent pore space of disturbed sandy clay loam soil versus tension.

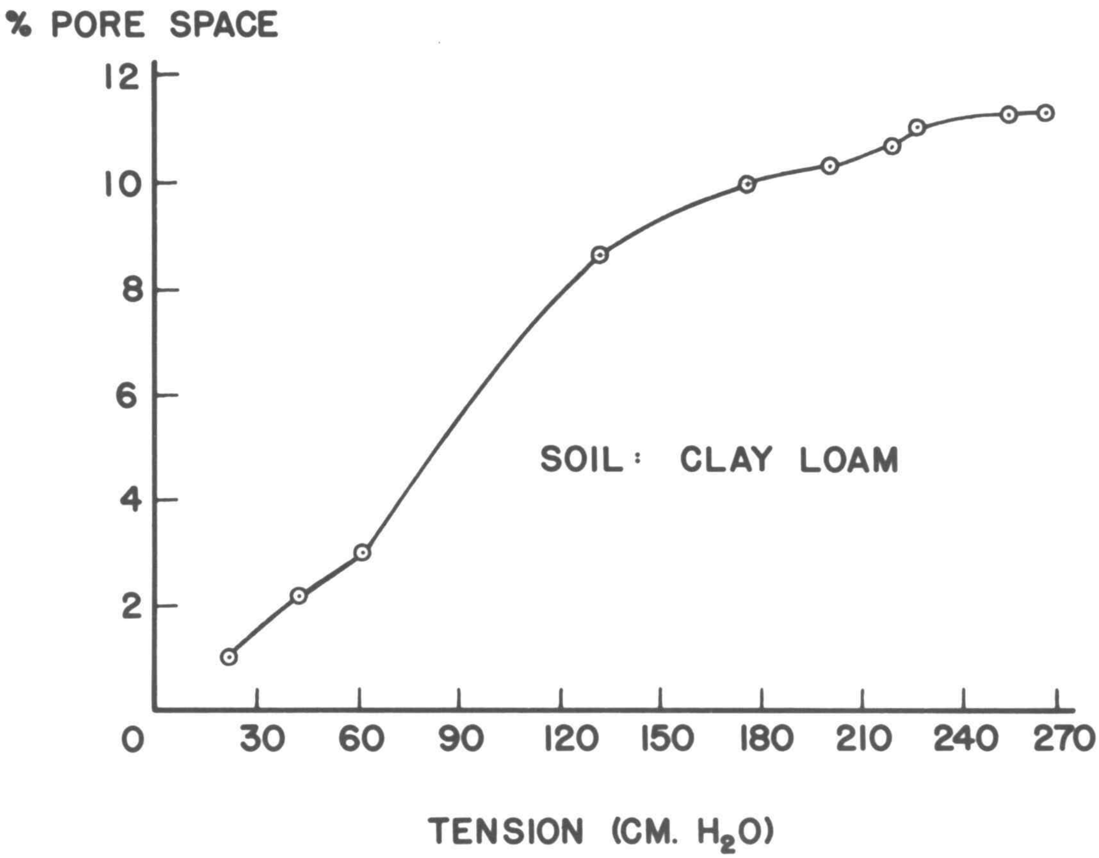

Figure 17. Percent pore space of disturbed clay loam soil versus tension.

These figures show that the relation between the air permeability of the samples, and the tension is similar to that of the percent pore spaces and tension. The results indicated that the percent pore spaces seem to have a considerable affect on the air permeability.

All the soil samples had a S-shaped curve when air permeability was plotted against their respective percent pore spaces. These results are presented in Figures 18-23. The saturated water permeability values were indicated on the graphs for comparison. The first part of the S-shaped curve was related to the fact that some of the pores were drained, but the connections between pores were restricting gas flow. Later, when the large pores were drained, the connections between pores improved; therefore, a rapid rise in air permeability was obtained. After the large pores were drained and the smaller pores started to drain, the increase in air permeability for a given change in pore space decreased.

Results for Core Samples:

The air permeabilities at the moisture content at sampling were plotted against the saturated water permeability of the samples, and the result is presented in Figure 24. As previously mentioned, each site was sampled twice, once when the moisture tension was around 100 cm. of water and another time when the tension was higher. Here again the bisector was drawn in Figure 24, and it also appeared to be the fit line for the data. The results are also presented in Table 2 in the appendix. The data indicate that air permeability at moisture tension about 100 cm. of water or higher, as recorded specifically in

Table 2, and the saturated water permeability of these samples were about the same.

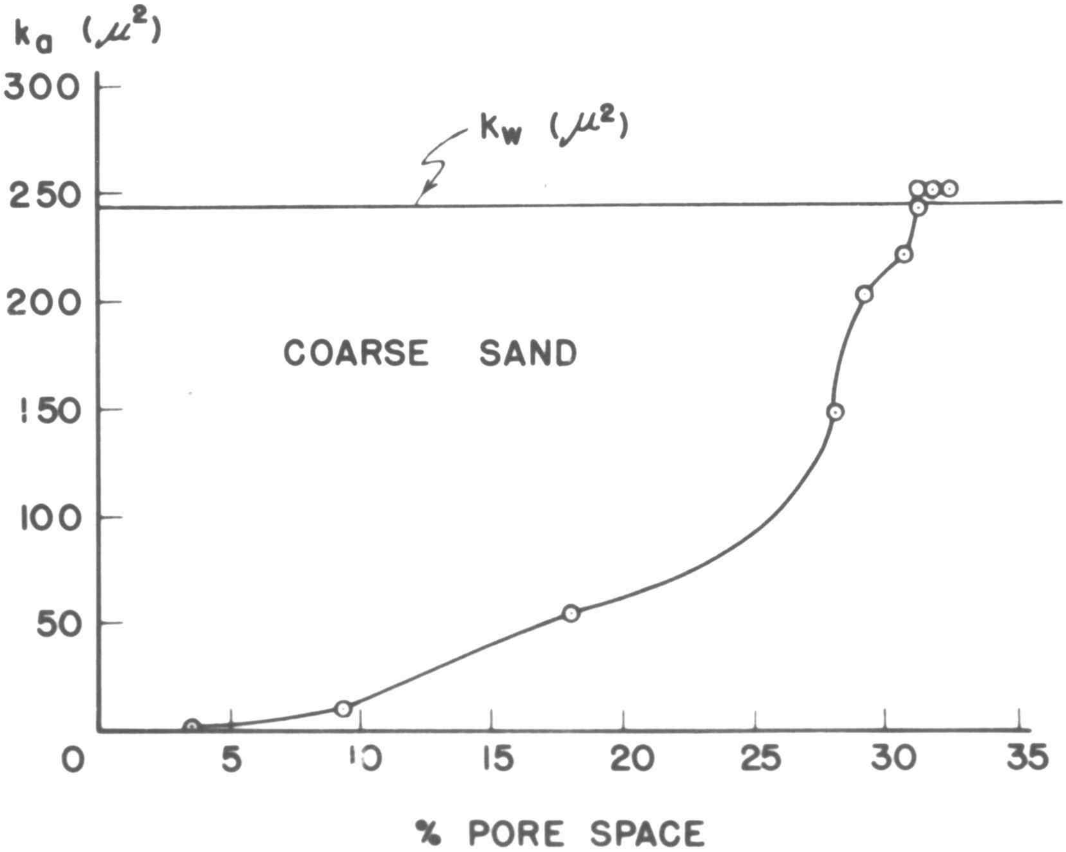

Figure 18. Air permeability of disturbed coarse sand versus percent pore space.

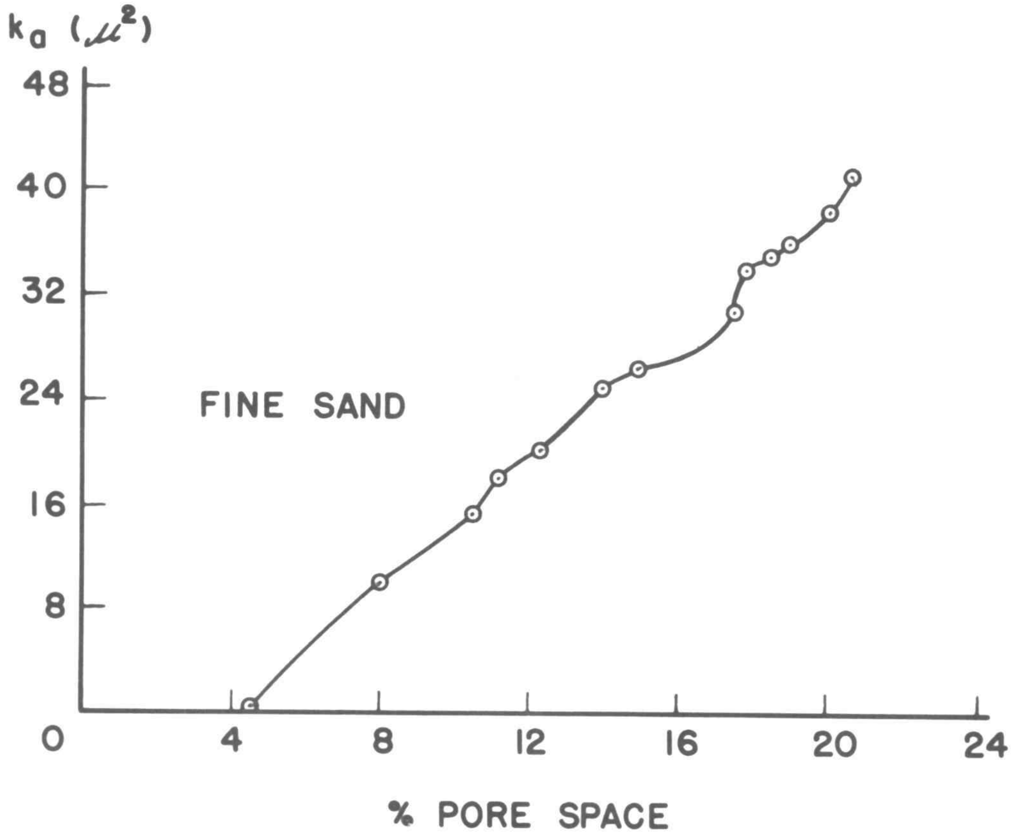

Figure 19. Air permeability of disturbed fine sand versus percent pore space.

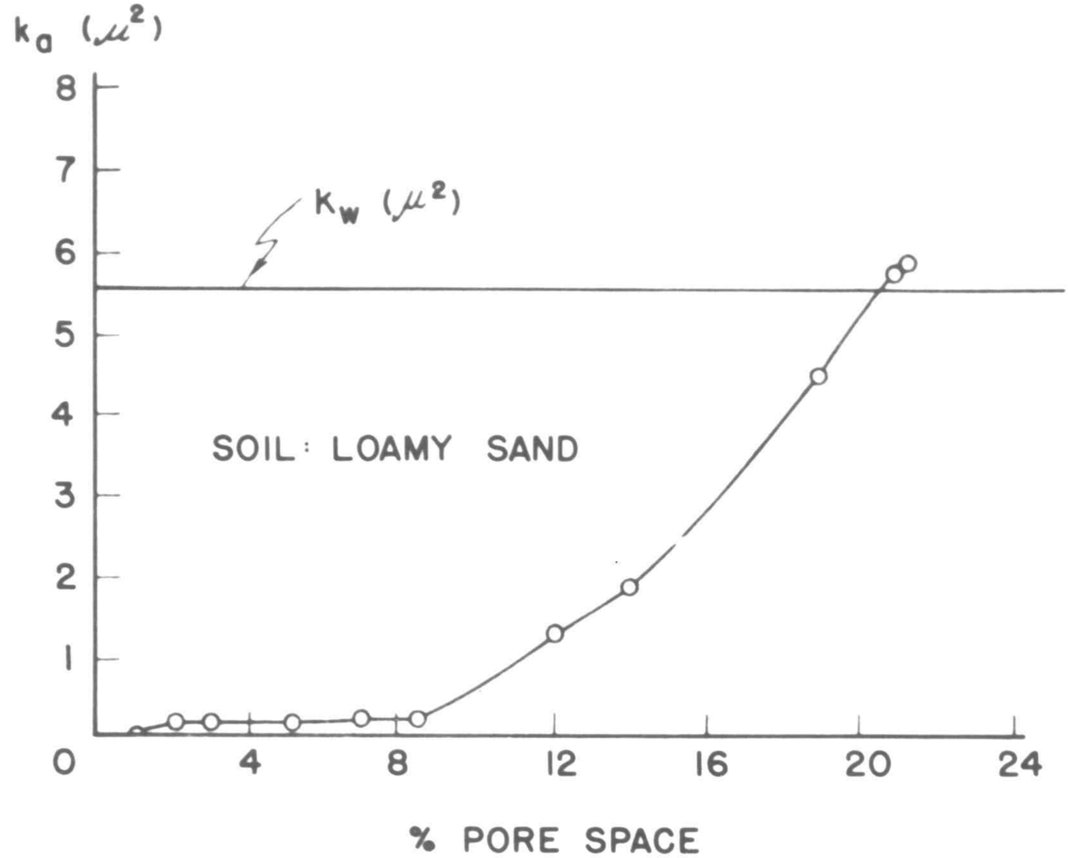

Figure 20. Air permeability of disturbed loamy sand soil versus percent pore space.

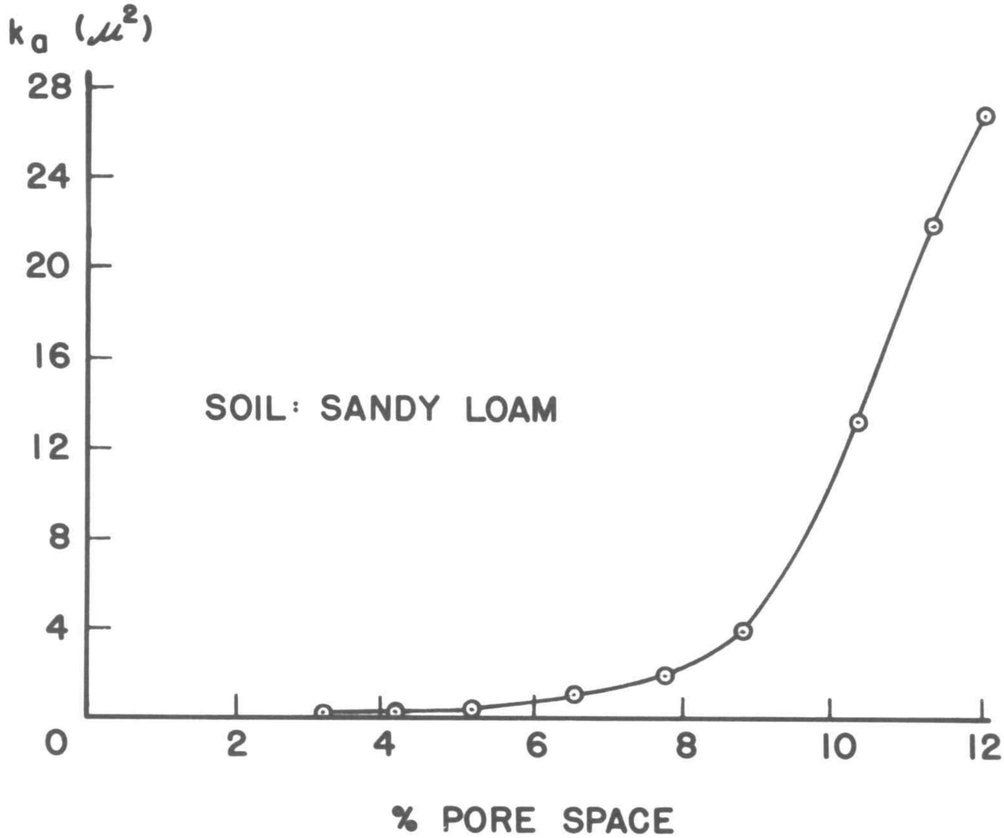

Figure 21. Air permeability of disturbed sandy loam soil versus percent pore space.

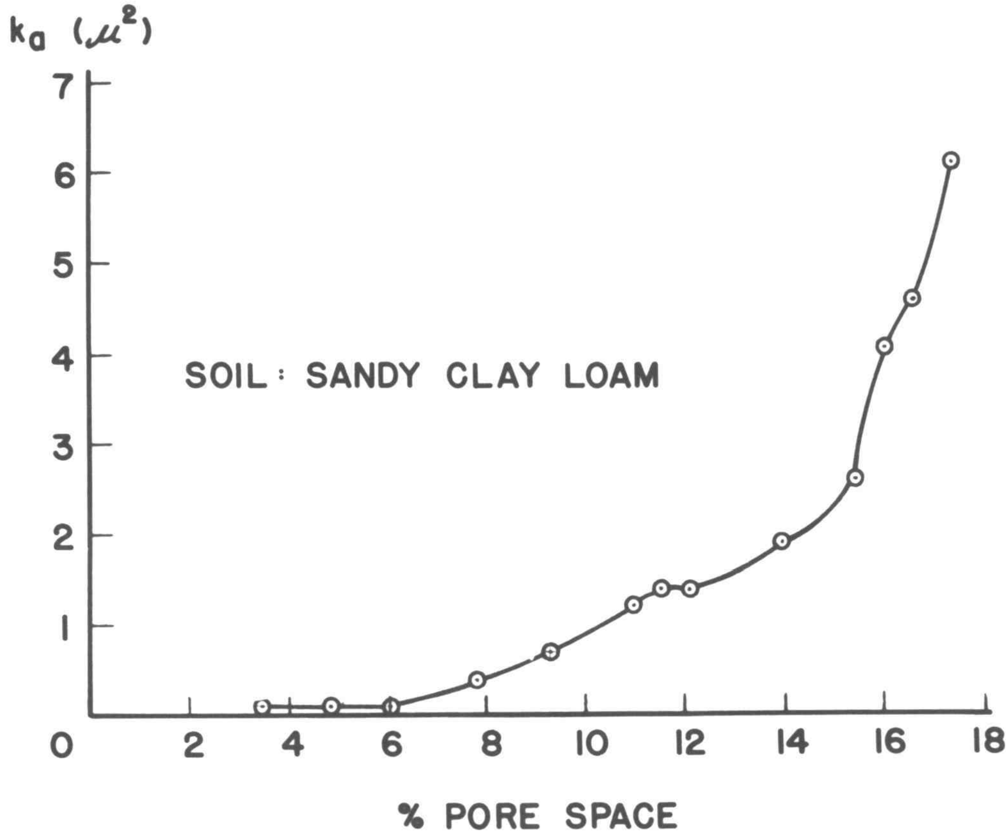

Figure 22. Air permeability of disturbed sandy clay loam soil versus percent pore space.

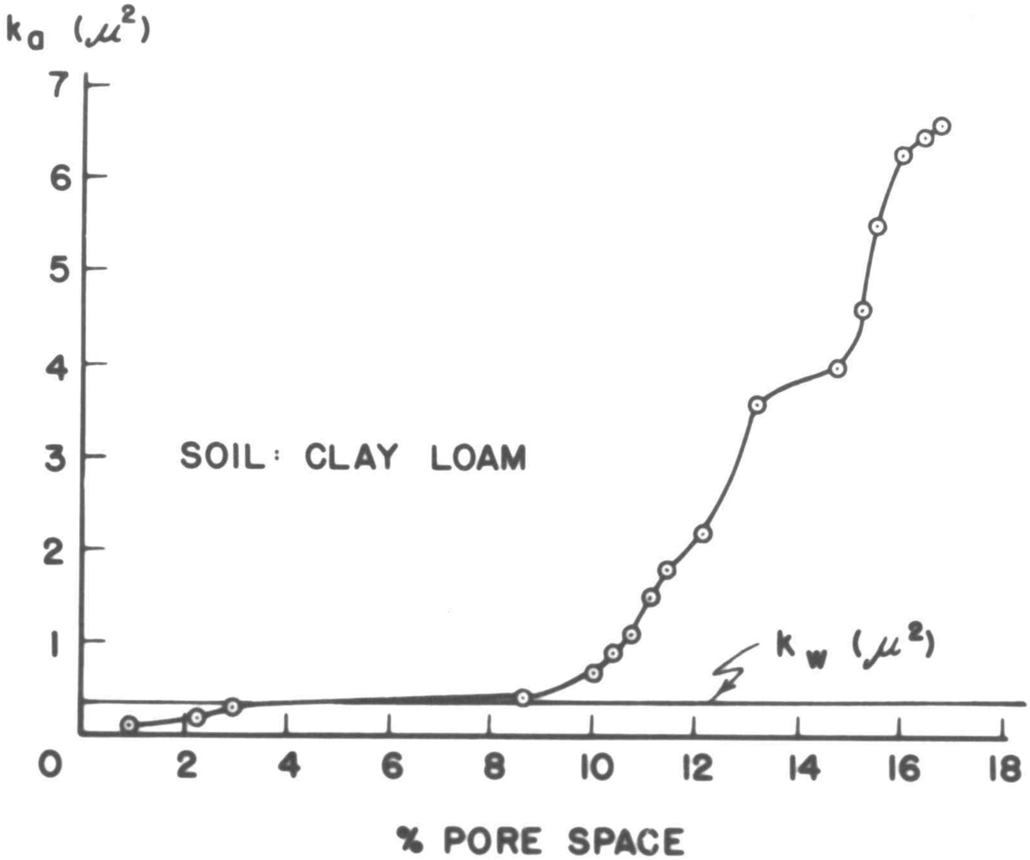

Figure 23. Air permeability of disturbed clay loam soil versus percent pore space.

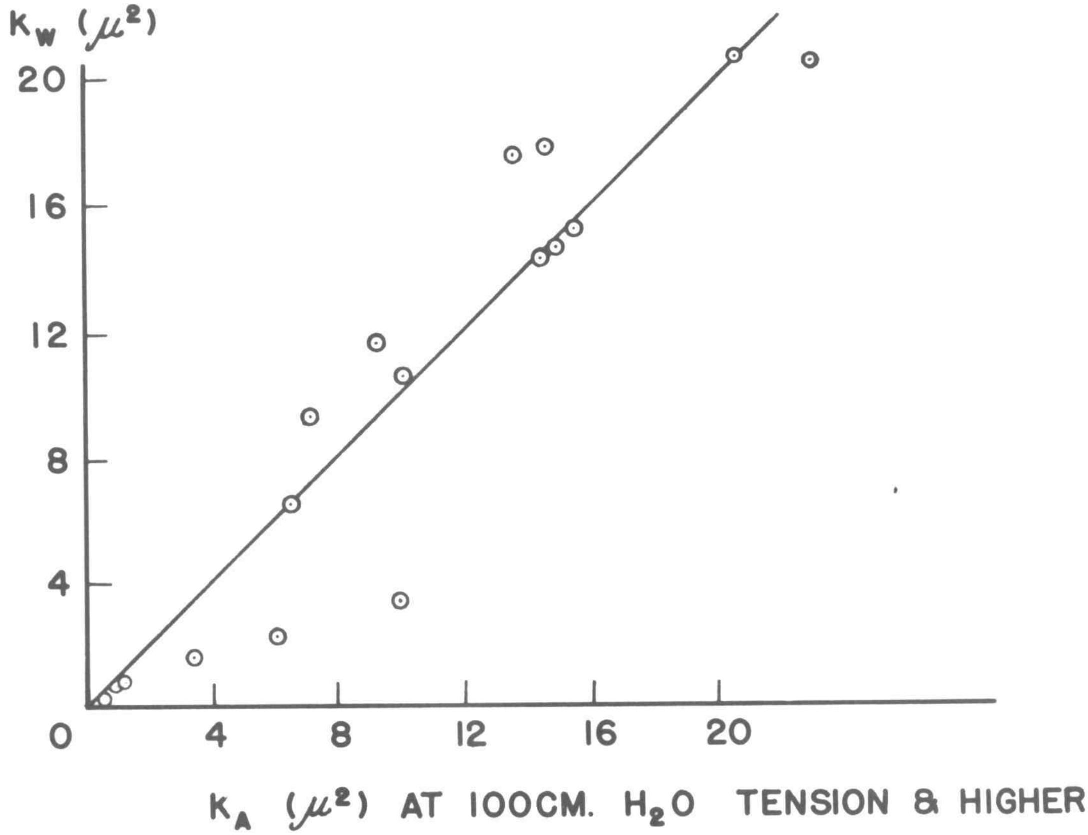

Figure 24. Air permeability of core samples at about 100 cm. of water tension versus saturated water permeability.

DISCUSSION

Today there is much interest in obtaining a reliable estimate of the saturated water permeability for soils to be used for drainage design and for characterizing soils. Several methods have been proposed but non is completly satisfactory. Some of the main limitations of the methods proposed are:

1. The measurement may consume a long time.
2. Some lack portability for use in the field
3. Some require the presence of a water table.
4. The accuracy of the measurements is limited in some cases to shallow depths.
5. The variation of the permeability within the soil profile cannot be shown.
6. The permeability obtained by some methods is an average value of the soil permeability over the entire profile.
7. The apparatus is often expensive and complicated.
8. When core samples are used to measure the saturated water permeability of the soil, the results are inaccurate because of the following reasons:
    a. It is difficult to obtain undisturbed soil samples.
    b. The pores can be plugged by foreign matter in the water.
    c. The microbial activity in the soil might plug the pores.

The results obtained from this study indicate that the measurements of the air permeability of the samples at a moisture tension close to 100 cm. of water give a reliable estimate of the saturated water permeability. According to these findings, a measurement of the air permeability in the field, when the moisture tension is about 100 cm. of water or higher, should give a reliable estimate of the saturated water permeability. A field apparatus needs to be developed for taking such measurement. The apparatus should be simple, portable, accurate and should not cause much disturbance to the soil structure during the act of measuring. The main limitation of this method will be the number of sites required for the measurement in order to obtain a reliable estimate of the permeability of the field. Although this method will have the above mentioned limitation, it still will be much superior to the others.

SUMMARY AND CONCLUSION

The main objective of this study was to evaluate air permeability as a means of estimating saturated water permeability in the field. Such information should yield a very helpful index in evaluating characteristics of a soil such as erodability, drainability, and aeration capacity with less limitations than the present methods of estimating soil permeability.

To accomplish the above objective, disturbed soil samples were taken from different soils of a wide range in texture. Saturated water permeability was measured, then followed by measurement of air permeability at different moisture tensions. All soils were flushed with CO_2 before measuring the saturated water permeability to eliminate the effect of entrapped air. The quantity of water which was extracted at each tension was measured and used in determining the percent pore space at that tension.

Tensiometers were installed in several fields of different soil texture. Core samples were taken around the area where these tensiometers were placed, and the moisture tensions in each site were recorded. Air permeability for these cores were measured at their field moisture content, then followed by measuring their saturated water permeability after they were flushed with CO_2. More core samples were taken from these sites when the soils were drier.

From the data obtained for the disturbed soil samples, it is obvious that air permeability at 100 cm. of water tension approached the saturated water permeability. Then the value of air permeability remained constant or changed very slightly when cracks did not occur, even when tension increased. The relation of the percent pore spaces and tension followed the same trend as that of the air permeability and tension. Air permeability of the core samples at moisture content around 100 cm. of water tension also were similar to that of the saturated water permeability. Air permeability changed very little when other cores were sampled from the same sites at higher moisture tension.

In conclusion it may be said that air permeability may be used as a means for estimating the saturated water permeability when the moisture tension is around 100 cm. of water.

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A P P E N D I X

APPENDIX

Table 1. Saturated water permeability of disturbed soil samples as related to air permeability at different moisture tensions.

Soil	Saturated Water Permeability	Tension (cm. H_2O)	Percent Pore Space	Air Permeability μ^2
Coarse sand	244.7	3.40	4.40	0.49
		11.30	9.25	10.13
		15.00	18.18	55.03
		17.10	27.76	149.22
		19.86	29.54	203.30
		23.75	30.45	224.01
		48.44	30.72	243.95
		87.40	30.85	252.05
		130.10	30.92	252.51
		165.20	31.17	252.53
		192.30	31.21	252.56
		202.90	31.28	252.58
Fine sand	26.69	11.20	4.46	0.45
		16.55	8.03	9.98
		28.04	10.40	15.60
		32.39	11.36	18.30
		40.30	12.24	20.50
		52.93	14.15	25.20
		65.10	15.06	26.55
		84.70	17.36	30.80
		95.50	17.82	33.00
		119.10	18.39	33.25
		133.50	18.94	35.90
		159.30	19.95	38.60
		184.90	20.64	41.20
		219.10	21.47	43.10
Loamy sand	5.51	6.40	1.10	0.0
		36.04	2.07	0.03
		51.00	3.17	0.03
		58.59	5.28	0.03
		64.62	7.17	0.14
		79.90	8.50	0.26
		79.92	12.12	1.32
		83.90	14.08	1.86
		90.22	16.39	2.99

Table 1. (Cont.)

Soil	Saturated Water Permeability	Tension (cm. H_2O)	Percent Pore Space	Air Permeability μ^2
Loamy sand (cont.)		102.90	19.12	4.46
		167.00	20.93	5.77
		173.80	21.24	5.88
		220.00	21.65	6.06
		266.90	23.07	7.43
Sandy loam	3.21	29.92	4.19	0.19
		34.80	5.27	0.31
		56.07	6.55	0.98
		67.62	7.83	1.98
		101.60	8.82	4.02
		126.70	10.34	13.25
		163.40	11.36	21.85
		177.40	12.07	26.80
Sandy clay loam	1.30	28.10	3.54	0.01
		47.50	4.99	0.02
		55.30	6.01	0.03
		62.23	7.87	0.40
		80.30	9.31	0.67
		91.00	10.98	1.22
		110.85	11.61	1.42
		128.10	12.17	1.44
		131.80	13.90	1.91
		192.50	14.92	2.41
		240.40	16.02	4.06
		264.00	16.63	4.63
		314.00	17.45	6.07
Clay loam	0.30	23.12	1.09	0.05
		43.09	2.25	0.15
		60.89	3.02	0.29
		151.20	10.00	0.56
		199.40	10.33	0.88
		218.00	10.77	1.11
		226.70	11.14	1.51
		263.30	11.58	1.85
		281.30	12.13	2.19
		320.40	13.44	3.63
		343.90	14.78	4.02
		359.60	15.22	4.63
		389.50	15.52	5.52
		440.00	15.96	6.28
		461.30	16.45	6.52
		475.70	16.67	6.58

Table 2. Saturated water permeability of core soil samples as related to air permeability at different moisture tensions.

Soil	Tension (cm. H_2O)	Air Permeability μ^2	Saturated Water Permeability μ^2
Fine sand	110	23.2	20.4
	110	20.6	20.6
	110	21.0	20.5
	140	23.1	
	140	21.2	
	140	23.0	
Sandy loam (Site 1)	100	14.9	14.7
	100	15.7	15.4
	100	14.5	14.4
	500	21.45	
	500	16.77	
	500	18.78	
Sandy loam (Site 2)	110	14.6	17.9
	110	10.2	10.8
	110	9.4	11.8
	450	18.343	
	450	11.434	
Sandy loam (Site 3)	120	13.6	17.5
	120	10.0	3.5
	500	14.68	
	500	14.90	
Sandy clay loam (Site 1)	110	7.2	9.4
	110	6.6	6.6
	300	8.2	
	300	8.4	
Sandy clay loam (Site 2)	120	6.0	2.3
	120	3.4	1.6
	300	9.6	
	300	7.9	
Clay loam (A horizon)	120	1.1	0.7
	120	0.9	0.7
	180	1.12	
	180	1.03	
Clay loam (B horizon)	140	0.4	0.2
	140	0.4	0.3
	140	0.4	0.3
	180	0.6	
	180	0.9	