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Measurement of Soil Hydraulic Conductivity and Site Selection for Liquid Waste Disposal

by

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Measurement of Soil Hydraulic Conductivity and Site Selection for Liquid Waste Disposal[1/]

by F. G. Baker and J. Bouma[2/]

Introduction

On-site disposal of liquid wastes in soil depends on one physical property of the soil itself--its hydraulic conductivity (K). While there are other limiting factors to the placement of soil adsorption fields, most of these are not inherent to the soil itself but are imposed on it by its surroundings, such as a high water table, or the presence of bedrock near the surface (11).

In selecting a site for liquid waste disposal it is essential to know the hydraulic conductivity of the soil at that location, not only at saturation (K_{sat}), but at a range of soil moisture tensions. This is important because soil moisture flow beneath a seepage field is usually unsaturated (5, 6). Predicting the behavior of a soil under an imposed moisture regime, as in the case of a seepage field, requires knowledge of these unsaturated conductivities. This is also needed to predict the effect of a biological clogging mat on the rate of adsorption (2, 3).

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The purpose of this paper then is to discuss: i) the measurement of soil hydraulic conductivity *in situ* by use of the crust test; ii) the variability of K in specific soil series; and iii) the use of this type of information for site selection of septic tank-soil adsorption systems.

1. Measurement of Hydraulic Conductivity Using the Crust Test Method

Although much use is made of the perculation test in site selection for home waste disposal systems (10, 11), much doubt has been cast on its validity as an accurate measure of the soil's ability to accept liquid (6, 8, 9). Much of the criticism arises from variable parameters of the three-dimensional flow involved and to the changing head applied. While it can be used as an indicator for the rough ranking of soil permeabilities, other tests are available that measure one-dimensional hydraulic conductivity rather accurately. The crust test method (4) is one of these techniques.

Preparation for the crust test method requires the carving out of a freestanding, *in situ* cylindrical pedestal of soil whose diameter is 25 cm and height is 30 cm. The topmost horizontal surface of the pedestal is in the upper portion of the horizon to be measured. The lower part of the pedestal is continuous with the underlying horizons, providing the pore continuity needed for an *in situ* method. A ring infiltrometer is fitted to the top of this soil pedestal. The upper horizontal surface of the pedestal becomes the infiltrative surface. The sides of the column are then covered with aluminum foil to reduce evaporation and pencil sized mercury tensiometers are installed three centimeters below the infiltrative surface.

Next a mixture of sand and gypsum is mixed thoroughly with water to make a uniform paste. The paste is spread evenly on the infiltrative surface and after good contact with the ring is assured, it is allowed to harden. This is the "crust" which acts as a resistant barrier to moisture flow. By varying the proportions of gypsum and sand in subsequent measurements one can change the crust's flow resistance. This resistance controls the liquid flux through the soil pedestal, inducing a specific tension in that soil.

Now that the pedestal is prepared, a plexiglass cover with two ports and a gasket is bolted to the ring and a burette with a Mariotte constant-head device is attached at one port. Water is applied through the burette until the system is purged of all air which exits via the second port. The system is then closed and positive head of less than 1 cm is applied. Flux is measured by volume change at the burette.

Flow is allowed to occur until an equilibrium flow is established with a hydraulic gradient of 1. Then K is derived from Darcy's law, $Q = KA$ where Q = flux, K = hydraulic conductivity and A = surface area of the infiltrative surface. The flow rate is determined from burette measurements and the tensiometer yields the matric potential.

For K_{sat} no crust is used since the maximum flow rate is desired. For this the aluminum foil is replaced by a plaster coating around the side of the pedestal. This prevents flow directly out the side of the column.

The rate of flow into the soil is governed by the crust. The crust resistance to flow--its Rb (3) is a function of the proportions of sand and gypsum in the crust--the higher the gypsum content, the greater the flow resistance--resulting in a lower flow rate. Each crust used yields a point on the K curve--for the soil at that site. This is illustrated in Figure 1, the actual hydraulic conductivity curve measured at a site in the B22t horizon of the Batavia silt loam.

Each point here represents the equilibrium condition for a particular crust whose gypsum content (by volume percent) is indicated for each point. It should be noted that equilibrium is approached by wetting, so that one begins the series of crust tests using the most resistant crust as a barrier to flow and proceeding to the next least resistant in order. This not only allows sufficient wetting time but avoids hysteretic effects. This test is rather time consuming and takes approximately three to four days per site.

2. Variability of Hydraulic Conductivity in Silt Loam Soils

A study was conducted during the summer of 1974 to determine the hydraulic conductivity characteristics of silt loam soils (1). The purpose was to study specific horizons of two representative silt loam soils--to measure their mean permeabilities and to establish the range of these permeabilities. This information is needed to be able to predict the hydraulic conductivities in identical soil occurring at a prospective building site. This had broad implications for determining the soil's potential for a given use.

Field work for this study was conducted around Dane County Wisconsin. This is in the southern part of the state, in the glaciated area. The soils here are, in general, formed in loess covering glacial till or outwash. Two soil series were studied--the Plano silt loam, a soil developed under prairie vegetation--and the Batavia silt loam, developed under forest. Their development, is quite different then, from a soil-genesis point of view. Their morphologies are distinctly different. We would therefore expect that a physical property such as hydraulic conductivity, which is at least a partial reflection of this morphology, would also be different for the two soils.

Within each of these soils, two horizons were studied, the B22t and the B31t. The upper boundaries of these horizons are approximately at 52 and 87 cm depth, respectively. Their structures are basically medium blocky for the B22t and prismatic or coarse blocky for the B31t horizons.

Six field sites were selected for each soil by a random method. Hydraulic conductivity (K) was measured in the two horizons at each site, using the crust test technique and an extension of this for saturated K. The desired levels at which measurements are made were determined by the soil morphology rather than using a fixed, predetermined depth, since thickness of overlying horizons was variable.

The frequency distribution of saturated hydraulic conductivity values was log-normally distributed and covered a broad range. If the logarithms of the data are used then normal statistical procedures can be applied.

An equation of this general form seemed to describe the conductivity data well:

$$\log K = \log(b\psi^{-c})$$

for $0.1 \text{ cm} \leq \psi \leq 150 \text{ cm}$, where ψ is the absolute value of the soil moisture potential (cm water) K is hydraulic conductivity (cm/day) and a, b and c are constants.

Each horizon of each soil was handled separately--totaling 4 data sets. Curves were fitted to these sets--2 horizons in the Plano, and 2 in the Batavia--using nonlinear regression. There appeared, however, to be no difference between the B22t horizon populations of Plano and the Batavia. The B31t horizon data were also alike.

So these data sets were combined according to horizonation. The resultant equations of regression of these data sets are shown here.

B22t horizon:

$$\log K = \log (5.44\ \psi^{-.487}),\ \text{with } s = 0.390 \qquad [1]$$

B31t horizon:

$$\log K = \log (4.77\ \psi^{-.466}),\ \text{with } s = 0.369 \qquad [2]$$

combining the data sets:

$$\log K = \log (5.10\ \psi^{-.478}),\ \text{with } s = 0.379 \qquad [3]$$

They are also very similar and when combined, yield a very similar equation. The difference between the hydraulic conductivities of the horizons was statistically insignificant. Reduced to simpler form, seeing that the exponent is nearly -.5 we have:

$$\log K = \log \left(\frac{b}{\sqrt{\psi}}\right) \qquad [4]$$

where by regression we find b = 4.96 or approximately 5.0 for the four sets of data combined and s = 0.367 indicating a relatively good fit.

In Fig. 3, the sample populations of the B22t horizons combined are presented in (a), the B31t horizons combined in (b) and for all four horizons in (c). There is essentially little or no difference between these populations and they become one. The centermost line (1) in each of the graphs (a, b, and c) represents the three descriptive equations (1, 2 and 4) of the data sets respectively. These represent the mean values of the populations. The pairs of lines bracketing the mean are the limits of the 68% and 95% prediction intervals for the populations. In Fig. 3 these are the pairs of lines--2 and 3--respectively. The intervals bounded by these lines indicates the range within which any future conductivity measurement will fall for each probability level. Although the ranges are broad, at least, some information can be gained from their use. For instance in c, lower line number 3 indicates with 97.5% assurance that any future value of K will be greater than the value indicated by this line. This means that we are 97.5% certain that any future value of K_{sat} (ψ_m = .1) will be greater than 100 cm/day. For higher tensions the conductivities at this level of probability drop off rapidly and would severely restrict use of these soils for liquid waste disposal if this level of reliability is desired.

It was concluded from this study that i) differences in the genesis of the two soils did not lead to noticeably different hydraulic conductivity characteristics, ii) that although the morphological structures of the two horizons studied are quite distinct their hydraulic conductivities are nearly the same, and iii) that although variability is fairly high, we can still define some of the limits of the conductivity in certain areas and apply this knowledge to uses that are affected by that property.

This indicates that even if variability of a soil horizon is rather high we can still predict what can happen in that soil when a drain field is placed in it and when a certain loading rate is applied (3). We do need this information at a particular site either from measurements made on location or by correlation with the same soil at other locations, including some information on the range of the conductivity values for any tension.

3. Three possible procedures for determining site suitability for septic tank seepage field construction based on permeability data

This leads to the consideration of methods to utilize this sort of information for predicting with a certain probability whether the hydraulic conductivity at a given site will allow a liquid waste disposal system to operate properly. There are three major possibilities available, following trends that are beginning to appear now (7).

The *first* of these is direct on-site testing of permeability at any new site. This is already required in many health codes (10, 11) as a means of evaluating a site. Use of the crust test would yield a K-curve for the soil. Sizing of the seepage system would then be based on the expected loading rate on the one hand and on the capacity of the soil to accept liquid on the other. The latter characteristic can be determined in several ways: (1) When existing seepage systems in these soils are generally clogged, moisture measurements can be made *in situ* in soil adjacent to these clogged systems to determine infiltration rates using K-curves. This approach was amply discussed in publications 3 and 5. (2) A most desirable flow rate (from a viewpoint of purification *and* adequate absorption) is defined for the soil on the basis of the K-curve if clogging is not expected to be a problem (see for an example, publ. 5). When clogging occurs, an equilibrium condition exists beneath the drain field. The soil moisture tension under the bed can be measured and this value extrapolated to other sites in similar soils. In this discussion the expected subcrust tension during clogging is called bp.

A *second* possibility would require a knowledge of the mean conductivity characteristic of soils at the series level and information on the variability of this property. To use these data, on-site determinations in specific soil series would be necessary and data for the series would be used for evaluation. The *third* scheme would eliminate any on-site field determination by the use of detailed soil maps already available in many areas from the Cooperative Soil Survey, U.S. Department of Agriculture. All of these possibilities have exceptions reverting the process back to the previous scheme for handling.

Figure 3 is a schematic breakdown of these three systems of site evaluation, indicating the major steps in the process. This scheme is based on the application of the conventional septic tank-seepage field system. It also assumes that other limiting conditions are screened out separately and that the conventional percolation test is the means of measuring permeability. However, the scheme is also valid for crust test data,and this aspect is most interesting. Using more advanced techniques to measure K could remove a great deal of slack at this stage and thereby increase the accuracy of any of these systems. This could also allow quantitative decisions to be made such as what alternate methods of disposal are possible and would allow a more accurate basis for sizing of the field. The diagram is self-explanitory but a few major points should be stressed.

3.1 System I.

I. is the decision making system used in Wisconsin and several other states. Based on percolation test data as well as other environmental factors construction is either approved or denied. Each site is tested separately. If it does not meet requirements, the owner must look for a site that will or he cannot construct a conventional system. If it passes, the field is sized according to percolation test data following empirical procedures which do *not* consider soil permeability alone (3, 6, 9). Use of the crust test would greatly improve the sizing procedure.

3.2 System II.

In II., a different approach is used. Based on accurate measurements, the hydraulic conductivity characteristics of major soil groupings are determined including variability data. This would follow much the same procedure as was described for the variability experiments presented in this paper. Some soil series would coalesce into conductivity groupings whose mean characteristics would be similar, so the number of these divisions would not be too large. A field determination as to which soil series occurs at the site would then lead to a realistic estimate of the conductivity characteristics of the site in question. Sizing follows procedures as discussed.

Figure 4 illustrates the range of possibilities that can arise under this scheme. The soil series at a given site has the K characteristic shown in (a). Here the soil is suitable because the lower limit for the prediction interval (P.I.) is above minimum K required at saturation and at the equilibrium tension (bp) at which clogging is expected to occur (3, 5). In (a) the variability is high (large range between the limits for P.I.) while in (b) variability is low. Both cases pass requirements because the required probability level (lower limit of P.I.) is satisfied, and a system is installed. In the case of (c) the variability is high. The lower limit (LL) of P.I. is below the minimum K at the predicted clogging tension, so we do not have the required level of confidence that the site will meet requirements. On-site testing of K is required. In (d) the same decision is made. $P.I._{LL}$ is below minimum K,even though variability is low (narrow prediction interval). On-site testing is required but the odds of finding a suitable site are less because the probable range of values is largely below the required minimum K. In (e) the entire prediction interval is below the minimum K. The site is turned down because of the high probability that it will not meet requirements. There is the outside chance that the site might with on-site testing yield a useable value, but these odds are low.

In such a scheme obviously a great deal of information is required to establish the hydraulic conductivity characteristics of the possible soil series or groupings. In areas of highly variable soil groupings it might be more practical to simply perform on-site tests and eliminate the need for this system.

3.3 System III.

III. is an extension of II. Here soil maps are used for identification of the soil series or grouping at a given site. For this purpose it is important to know the amount of mapping error involved. In some areas mapping is more difficult than in others, leading to differing map reliabilities. In cases where the map is very reliable a decision is based directly on the data for that series, eliminating the need for an on-site visit. This site is then evaluated according to the advanced stages of II. Mapping reliability could be too low to allow this route and an on-site identification of soil series would then be needed proceeding with scheme II. It should be noted that the mapping reliability and the level of K probability for a site will compound. For certain soils this scheme can be very useful. In the central sand plains of Wisconsin, for example, the Plainfield Series can be mapped with very high reliability and its range of conductivities is generally always above the minimum K required. In this case, use of the soil map can save a great deal of time in site selection. Scheme III then relies not only on soil mapping but also on determination of K data and variability of the soils involved.

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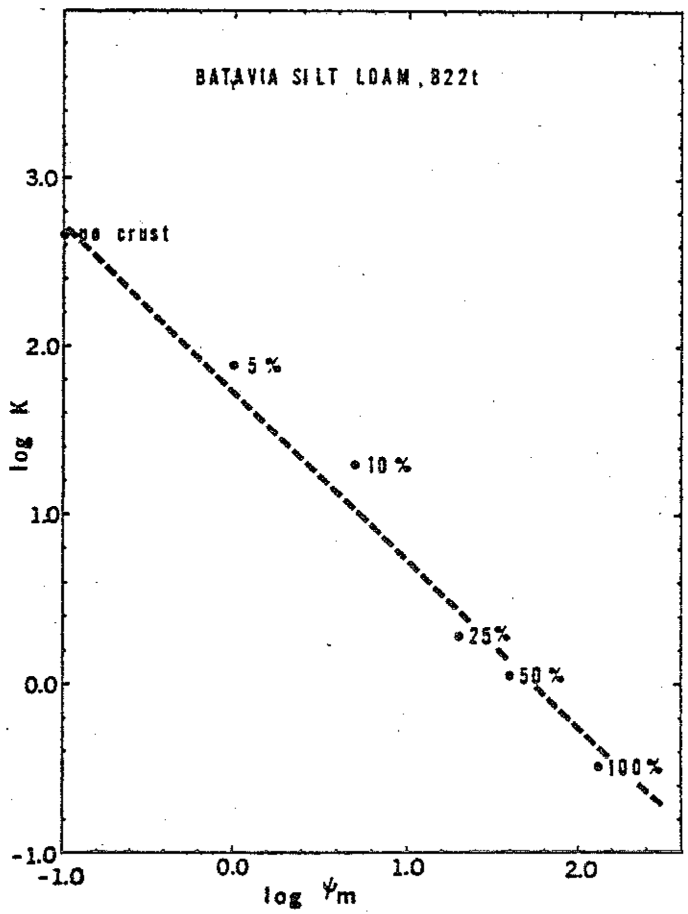
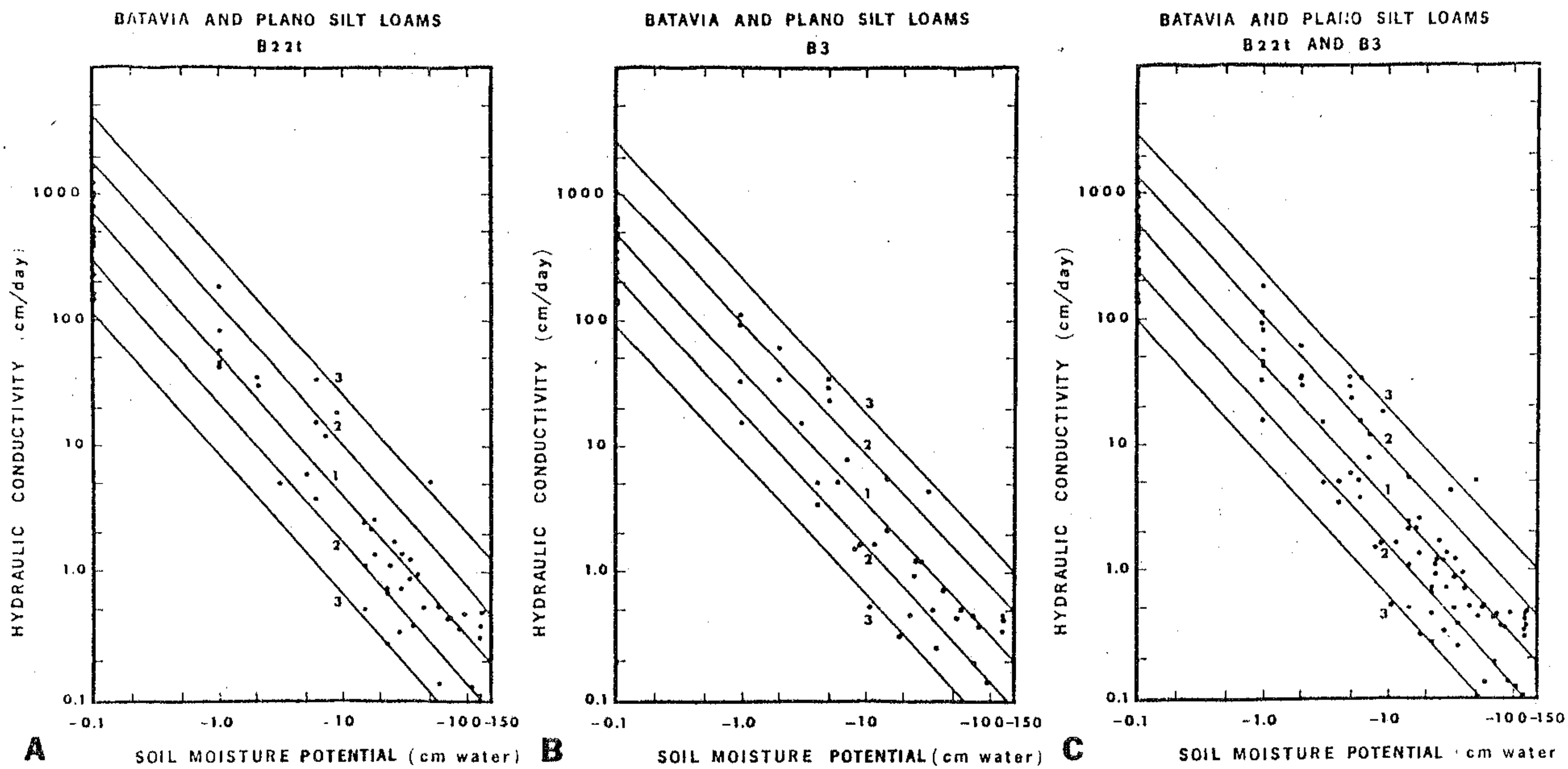
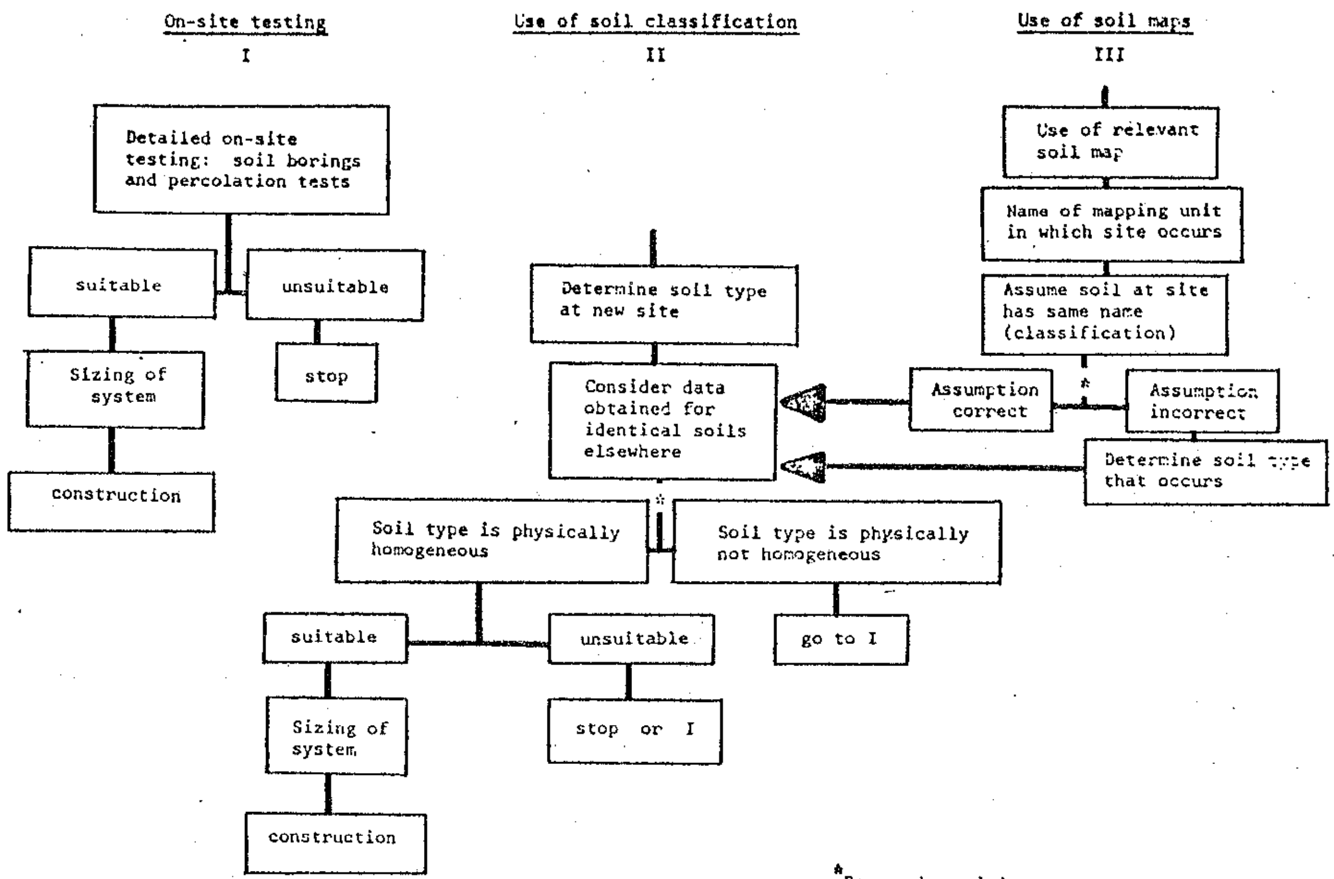

BATAVIA SILT LOAM, 822t
3.0
2.0
1.0
0.0
-1.0
log K
no crust
5 %
10 %
25%
50 %
100%
-1.0
0.0
1.0
2.0
log ψ_m


BATAVIA AND PLANO SILT LOAMS
B22t
HYDRAULIC CONDUCTIVITY (cm/day)
1000
100
10
1.0
0.1
-0.1
-1.0
-10
-100-150
SOIL MOISTURE POTENTIAL (cm water)
A
BATAVIA AND PLANO SILT LOAMS
B3
HYDRAULIC CONDUCTIVITY (cm/day)
SOIL MOISTURE POTENTIAL (cm water)
B
BATAVIA AND PLANO SILT LOAMS
B22t AND B3
HYDRAULIC CONDUCTIVITY (cm/day)
SOIL MOISTURE POTENTIAL cm water
C



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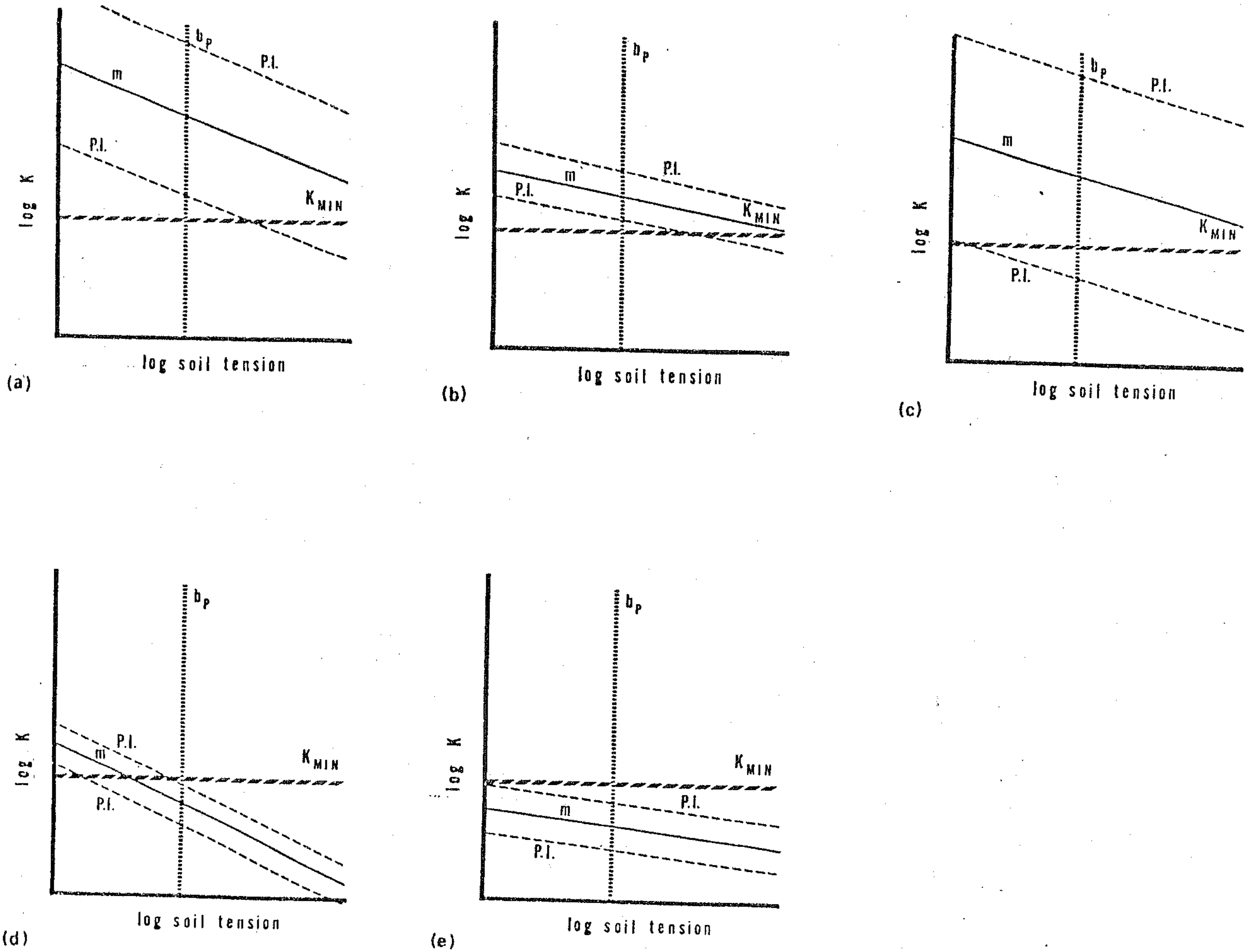
log K
log soil tension
(a)
(b)
(c)
(d)
(e)
m
P.I.
b_p
K_{MIN}