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MOISTURE RETENTION BY SOILS

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1. APPEARANCE AND BINDING OF MOISTURE IN THE SOIL

A moist soil, that is a soil not saturated with water, is a three phase system, consisting of a solid phase (the soil), a liquid (the soil moisture) and a gaseous one (the soil air). We shall occupy ourselves in this paper mainly with soil moisture and especially with the concerning statical problems. The dynamical (flow) questions will be treated by WESSELING (1960) and WIND (1960).

It must be stated that generally soil moisture is a solution containing different salts, their ions and also the cations, dissociated from the humus and clay colloids. The concentration of this soil solution however is under humid circumstances as in the Netherlands mostly so low (in the order of 0.5 g/l; seawater 35 g/l); that we may neglect it for practical purposes. Naturally the concentration is increasing with decreasing moisture percentage, but generally we don't allow for it on the agricultural important part of the moisture percentage scale above the wilting point.

The soil is a building consisting mainly of inorganic and organic particles, which are hold together by means of different forces. The nature of this building is called *soil structure*. Between the soil particles there is always a network of cells of all kinds of shapes and sizes, the *pore space*, which is containing the soil moisture.

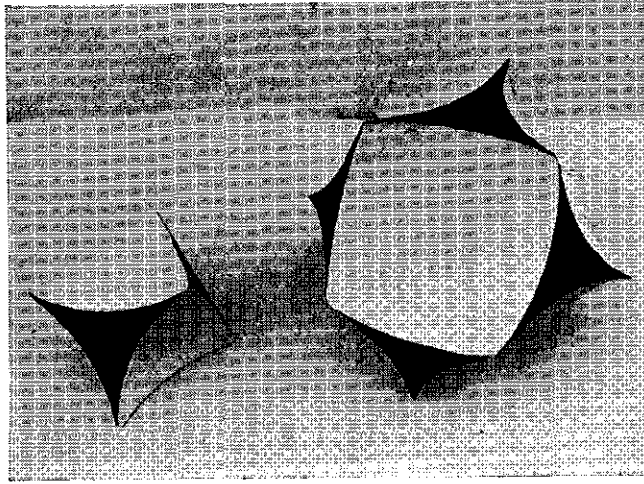
The geometry of the pore space is very complicated. Scientists as SLICHTER (1897/'98), VERSLUYS (1916) and HAINES (1927; 1930), who based their theories on soil moisture on the geometry of the pore space, were obliged to work with a very simplified soil model. Generally they used what VERSLUYS was calling an "ideal earth", a close or open packing of uniform spheres. Even then the pore space is fairly complicated. It is a network of tetrahedral and rhombohedral cells, which are bounded by 4 and 8 curved surfaces and are connected by 4 and 8 triangular apertures (pores) respectively. Figure 1 shows plaster casts of both types of cells.

Forces of several kinds are working on the soil moisture:

- a. *attracting forces originating from the surface of the soil particles*. Generally these adhesive forces are greater than the cohesive ones in the soil solution, thus making the soil particles wettable very well. Among these attracting forces LONDON-VAN DER WAALS-forces are always playing an important part. On the surfaces of colloidal clay and humus particles however they are strongly supported by electrostatical forces arising from the negative charge, which is attracting the positive side of the water dipoles. These electrostatical forces are responsible for the great hygroscopicity of clay and humus.

FIG. 1.

Plaster casts of a tetrahedral (left) and a rhombohedral (right) cell of the pore space in a dense packing of uniform spheres. Each rhombohedral cell is surrounded by 8 tetrahedral ones. The boundary-surfaces are white, the connecting pores black.



- b. *capillary forces*. They are resulting from the combined play of the cohesion of soil moisture and the adhesion between soil and moisture if there is an interface between soil moisture and air. The capillary forces are trying to reduce the size of these interfaces as far as possible; they are drawing back soil moisture into annular rings around the points of contact of the soil particles. Their magnitude is depending on the size of the air-moisture interfaces, thus on pore-size, and on the surface tension of the soil solution, which depends on temperature and salt concentration of soil moisture.
- c. *hydrostatical forces* arising from gravity.
- d. *osmotal forces*, which have only an influence if the salt concentration is high enough and if a semi-permeable wall is present. The osmotal forces are unimportant under normal Dutch field-circumstances.
- e. *forces put on by soil air*. Smaller or bigger quantities of air can be entrapped in the soil and put a pressure on soil moisture (Cf. the Lisse-phenomenon; THAL LARSEN (1930)).

The forces mentioned under *a*, *b* and *c* are the most important ones, the others are exerting an influence only under special conditions and will be neglected here.

If a soil saturated with water dries up, air enters the pore space and moisture is drawing back into thin layers on the surfaces of the soil particles and in the V-shaped rings around their points of contact. In this state, which has been called by VER-SLUYS (1916) the funicular stage, an eventual moisture movement occurs within these thin layers along the surfaces of the soil particles. If moisture percentage is decreasing further, the annular moisture rings are losing their contacts (pendular stage). Then movement of moisture is only possible in the vapour state and therefore quantitatively very small.

It will be clear that owing to the complexity of the pore space as well as to the diversity of forces, quantitative descriptions of soil moisture, based on soil models and theory of capillarity, have had only a limited significance. Therefore one was trying in an early stage to eliminate the geometry of pore space and the diversity of forces by introducing energy relationships in the study of soil moisture retention.

2. THE ENERGY CONCEPT IN SOIL MOISTURE RETENTION

The energy concept in the theory of soil moisture is introduced by BUCKINGHAM (1907) and further developed by GARDNER (1920), RICHARDS (1928), SCHOFIELD (1935), EDLEFSEN and ANDERSON (1943) and others. Both last mentioned scientists have given a detailed thermodynamical treatment of soil moisture.

The application of energetics in soil moisture studies is based on the concept of *free energy*. This energy concept is characterizing the state of energy of a system with respect to a certain reference level of energy and equals the total energy, which will be liberated (usually in two or more varieties) if the system transfers from the state under consideration to that of the reference level. The *specific free energy* e_s can be defined as the free energy per unit of mass (expressed in ergs/gram).

Now let us consider a soil column S (fig. 2), placed with his lower end in an open tank T filled with water.

The water surface in the tank may be the reference level with zero free energy. If water will be raised from point A on the reference level to point B, lying in a free water surface at a height h above A, there will be an increase of the specific free energy of gh (g = acceleration due to gravity) and hence the specific free energy at B will be $e_s = gh$.

If moisture in S is in equilibrium (the statical state), then free energy in each point of the moisture in the soil column must be zero; so in point C at a height h above A too. Consequently bringing water from B to C and supposing there will be moisture equilibrium in C after that, specific free energy must decrease gh . This is the *specific retention energy*, which is liberated if water is added to a moist soil.

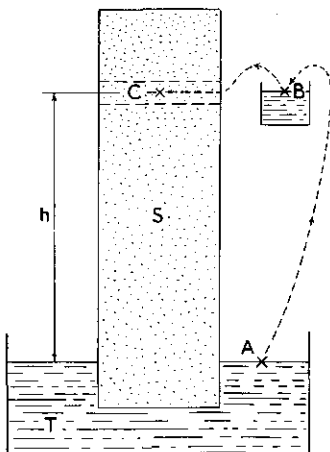


FIG. 2.

Imaginary experiment for determining the moisture potential in a soil column, which has a water table and is in moisture equilibrium. Cf. text.

Therefore specific free energy of soil moisture, which is in equilibrium at a height h above the water table, consists of two parts:

- a. the specific potential energy in the field of gravity being equal $+ gh$;
- b. the specific retention energy of soil moisture being equal $- gh$.

Mostly one is not speaking about the specific retention energy, but about the *moisture-potential*. If the mass-unit of moisture is transported from B to C (fig. 2) the work-done equals $- gh$. Therefore moisture potential in a certain point of the soil can be defined as the work, which one has to do if the unit-mass of water is transported from a free water-level at the same height to this point.

3. DETERMINATION OF MOISTURE POTENTIALS AND -CHARACTERISTICS

As an attempt to measure the moisture potential of a moist soil sample one could place it on a sand column and try to adjust the water table in such a way, that there would be no exchange of moisture between sample and sand column. If it appeared that the phreatic level must be h cm below the centre of the soil sample the moisture potential would be $- gh$ ergs/gram.

It is very difficult however to adjust in this way a moisture equilibrium and besides it is more important generally to determine on the soil sample the relation between moisture potential and moisture percentage, the so-called *moisture characteristic*, than the moisture potential at the moment of sampling only.

To determine the lower part of the moisture characteristic an undisturbed soil sample (obtained in a rustless steel cylinder with a special auger; see fig. 3), which has been saturated with water previously, is placed on a sand-layer with an adjustable water table.

The apparatus is shown in the figures 4 and 5. An iron tank (30 x 60 x 40 cm) is provided with a drain system (made of copper tubes with bore-holes in the lower-side and covered with nylon cloth) and filled with 31 cm fine sand (so-called Blokzijl sand, containing about 57 % fraction 50-75 μ and 22 % fraction 35-50 μ), which is covered by a layer sifted sandfraction 35-50 μ , about 5 mm thick. The surface of this layer is covered with a nylon cloth (see fig. 5). The drain system is

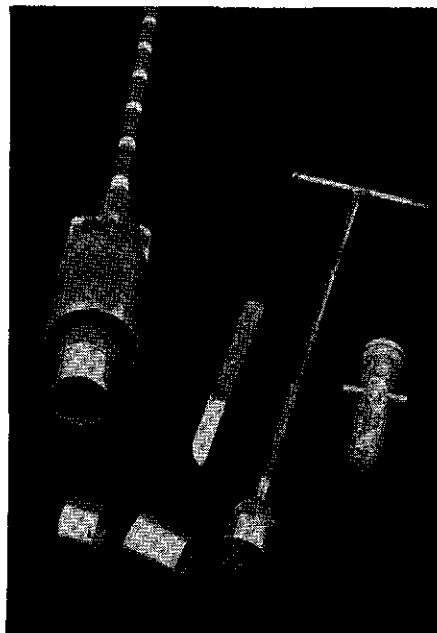


FIG. 3.

Two types of augers to obtain undisturbed soil cores in rustless steel cylinders for soil physical determinations. Diameter and height of the cores 5 cm. See for the type at the left KUIPERS (1955), page 21-22.

connected with a level-bottle (fig. 4, right) to adjust the water table.¹ Due to the fineness of the sand in the top-layer it is possible to drop the water table up to more than 100 cm below the centres of the samples without air entering the sand layer. Thus the sand stays in the funicular stage and moisture movement is possible pretty well.

The apparatus has several advantages over the usual ceramic plates:

- a. A better moisture contact of the samples with the underlayer and consequently a quicker and better adjustment of equilibrium (cf. fig. 5; the samples are pressed into the sand a little bit).
- b. No difficulties with stoppage of the under-layer by algae, fine particles a.s.o.; the sand surface can be broken up and cleaned or replaced very easy if necessary.
- c. It is possible to treat a large number of samples (here 50) at the same time on one apparatus, which is pretty cheap.
- d. The samples can be saturated with water on the same apparatus by raising the water table up to about 3 cm above the surface of the sand layer (adjusting time: 3 days).

After saturating the samples the water table is adjusted in the surface of the sand layer. Since the height of the samples is 5 cm, the moisture potential in the centre of the sample is then -2.5 g ergs/gram (pF 0.4; see par. 4). The moisture equilibrium is attained after about an hour. Then the samples are weighed and replaced on the apparatus, where-upon the water table is adjusted 7.5 cm below surface or 10 cm below the sample centre. After 7 days² the samples are reweighed. Moisture potential is now -10 g ergs /gram (pF 1.0; see par. 4). Determination of sample weights at moisture potentials of -30 g and -100 g ergs/gram (pF 1.5 and 2.0 resp.; see par. 4) occurs in the same way. Finally the sample is dried at 105° C and moisture percentages at the different moisture potentials can be computed.

For the moisture potentials -200 g and -500 g ergs/gram (pF 2.3 and 2.7 resp.; see par. 4), which are determined with the aid of ceramic filter plates till now, a similar technique is under development. Hereby a sank tank is used with a top layer of kaolin and the suction of the low water level is replaced by that of rarefied air. On this subject will be reported later.

A pressure membrane after RICHARDS (1947) is used for the determination of the moisture characteristic in the potential range between -1000 g and -20000 g ergs/gram (pF 3.0 - 4.3; see par. 4). The apparatus is shown in the figures 6 and 7.

For the methods mentioned above it is very important that there is a continuous moisture film throughout the soil sample at the beginning of each drying period and that there is always such a film throughout the base of the soil sample and the underlying layer (sand, cellophane etc.). It is possible only under these circumstances to withdraw the greater part of the moisture in the liquid state, that means within a

¹ The technical working-out of the apparatus is from mr. A. L. VAN LOKHORST. A detailed description is obtainable from the authors on application.

² Probably a shorter period is sufficient. This problem is still under investigation.

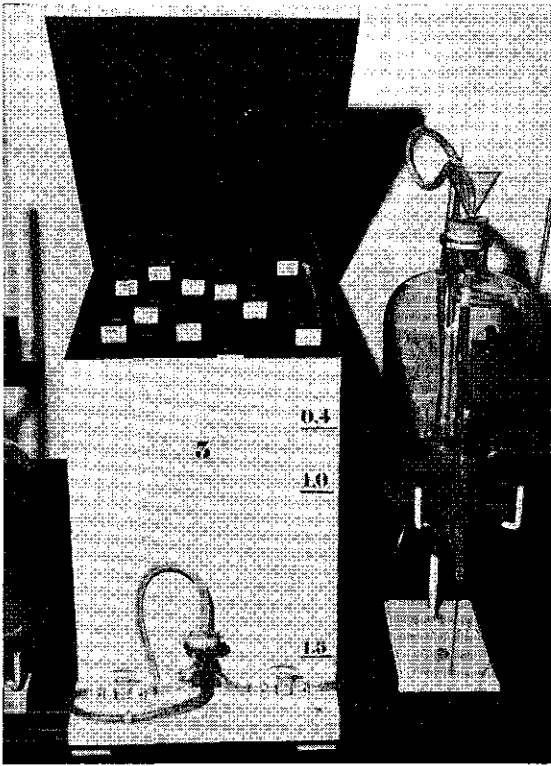


FIG. 4.

Apparatus for the determination of the moisture characteristic up to a moisture potential of -100 g ergs/gram (pF 2) *. Right: the level-bottle, which here is adjusted on a moisture potential of -10 g ergs/gram (pF 1.0). The sand tank can be closed with a wooden cover.

* See for definition of pF par. 4.

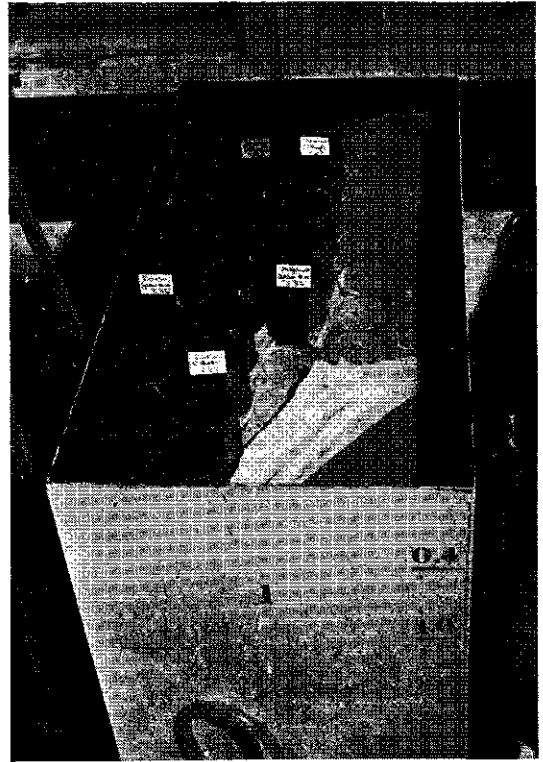


FIG. 5.

Top of the sand tank (see fig. 4) with undisturbed soil samples in rustless steel cylinders. The nylon cloth is turned back partly to show the surface of the sand layer.

reasonable short time. Measuring the moisture percentage of a soil sample however at very low moisture potentials (say f.i. $-1\ 000\ 000$ g ergs/gram) the sample must come by way of the vapour phase into equilibrium with a body of constant moisture potential. As such a body we are using the atmosphere in a room of our building. Its relative humidity is determined by means of a respiration hygrometer.

The relation between the moisture potential ($-gh$ ergs/gram) and the relative humidity of the soil air ($r\%$) is derived thermo-dynamically by SCHOFIELD (1935):

$$-gh = -\frac{RT}{M} \ln 100/r$$

in which R , T and M are the molecular gas constant, the absolute temperature and the molecular weight of water respectively. Substitution of the constant values gives:

$$h = 1.08 \times 10^4 \times T (2 - \log r) \text{ cm.}$$

Using small (disturbed) samples (about 7 grams of moist soil spread in a fairly thin layer in a porcelain cup) equilibrium is obtained after about 6 days. Then moisture

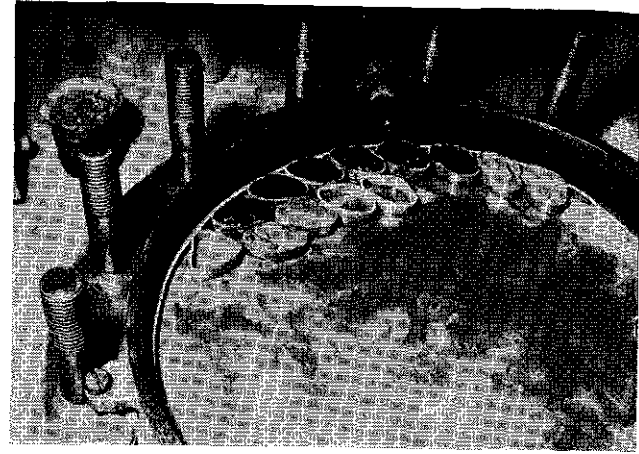


FIG. 7.

Interior of the pressure membrane. Wetted (disturbed) soil samples in triangular plastic rings on the cellophane membrane.

FIG. 6.

Pressure membrane (dismounted) for the determination of the moisture percentages at moisture potentials of -2500 g and -16000 g ergs/gram (pF 3.4 and 4.2 resp.; see par. 4). At the left from the bottom upwards: brass base with outlets and screen, cellophane membrane, rubber gasket ring, cylindrical side wall of the pressure chamber and pressure-gauge.

percentage of the soil can be determined and moisture potential can be computed from the relative humidity of the air by means of the formula.

All methods mentioned above are based on the principle of bringing a moistened soil sample into contact and into moisture equilibrium with a system of a constant, but adjustable moisture potential (top of the sand layer, cellophane membrane etc.). For the determination of the moisture potential in situ however a system with measurable moisture potential must be brought into moisture equilibrium with the soil, without changing the moisture potential of the soil. Such well-known systems are for instance:

- a. a cone-shaped plaster cup with a weighable plaster plug in it (DAVIS and SLATER (1942) fig. 8),
- b. a porous ceramic tensiometer-cup (fig. 9),
- c. any type of electrical resistance block (see f.i. fig. 10).

A good moisture contact between the measuring system and the soil is very important.

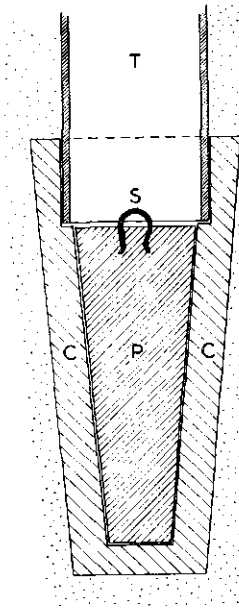


FIG. 8.

Weighable plaster cone for the determination of the moisture potential (cross-section). C = cone-shaped plaster cup, imbedded in the soil. T = plastic connecting tube to the soil surface. P = plaster plug, which on the suspension-eye S can be brought through T to the surface and be weighed. The relation between the weight of the plug and the moisture potential must be determined empirically (see for the utility range fig. 11).

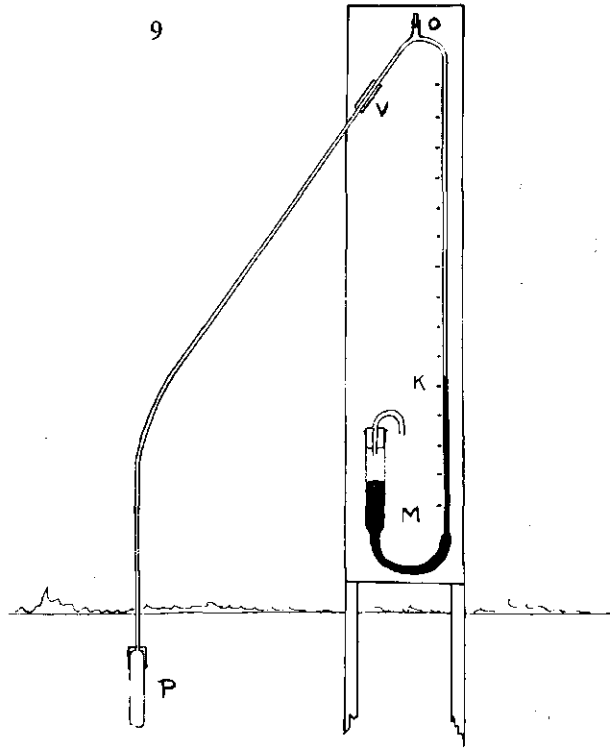


FIG. 9.

Tensiometer. The porous cup P, which is embedded in the soil, is connected by means of a thin brass tube with the mercury manometer M. O is an airtrap. The part PVOK is filled with water. The manometer reading, transferred in cm/water (h), gives the moisture potential — gh. Only usable up to about h = 500 cm.

4. MOISTURE TENSION AND PF

As is mentioned in par. 2 moisture retention can be characterized by the moisture potential. In par. 3 we saw that in many cases moisture potential is measured as the length of a water column. Therefore it was becoming a custom to express moisture potential not in ergs/gram, but to characterize it by means of a tension in cm water column or in atmospheres, the so-called *moisture tension*. Moisture potential and moisture tension are related quantitatively as follows:

$$\text{moisture tension (in cm water column)} = -\frac{1}{g} \cdot \text{moisture potential (in ergs/gram)}.$$

Since moisture tension is increasing rapidly in a drying soil it is more practically to work with the logarithm of moisture tension than with this tension itself. SCHOFIELD

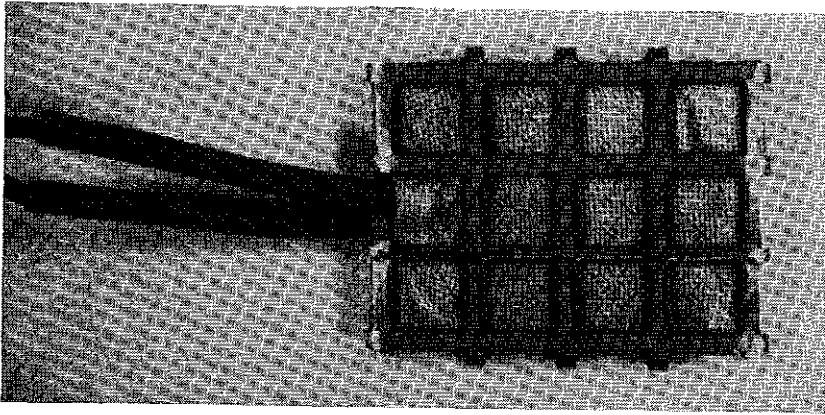


FIG. 10.

Nylon resistance unit after BOUYOCOS and MICK (1948). Two wire-gauze electrodes are wrapped with nylon cloth and locked in a metal cage. The unit must be gauged. The relation between resistance and moisture potential is depending somewhat on temperature. Therefore parallel-measurements with resistance thermometers are necessary. Usable up to the wilting point (see fig. 11).

(1935) therefore introduced for the 10-logarithm of the moisture tension in cm water column the symbol pF (p = power of 10; F = free energy). A moisture characteristic in which the pF is plotted against moisture percentage is called a pF -curve.

Fig. 11 is summarizing the different moisture scales and the ranges of the principal measuring methods.

5. MOISTURE CHARACTERISTICS AND CHARACTERISTIC STATES OF THE MOIST SOIL

A moisture characteristic is giving full information on the relation between moisture tension and moisture percentage over the entire range from wet to dry. Before these characteristics were common property, and still now, one was trying to typify the soil moisture relationship by means of the moisture percentage at a characteristic moisture state of the soil, e.g. maximum moisture holding capacity, field capacity, moisture equivalent, wilting point etc. We will treat here the field capacity and the wilting point only.

Originally *field capacity* has been defined as the moisture percentage of a soil 2 or 3 days after irrigation or heavy rainfall, so that the excess of water could drain away. In that way an accurate determination is possible only on soils, which show a sudden fall of the capillary conductivity, as f.i. well graded sands. Most soils however have a regular changing capillary conductivity and consequently the empirical determination of field capacity is somewhat obscure. A better starting-point is a well chosen moisture tension. For Dutch circumstances this appeared to be about pF 2. The moisture percentages in early spring of the Dutch soils with low ground-water levels are corresponding on the moisture characteristics namely with pF -values in the neighbourhood of 2. This is a somewhat lower value than is mentioned generally in literature, what may be caused by the following facts:

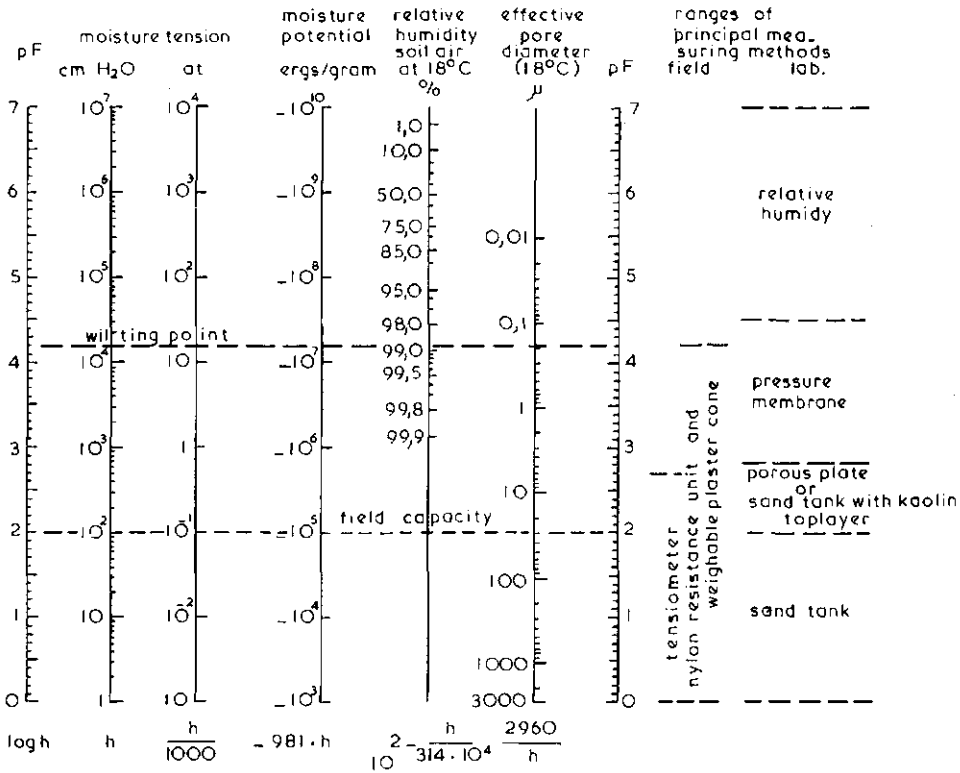


FIG. 11.

Comparison of the moisture potential, tension, pF, relative humidity and effective pore diameter scales; ranges of the principal measuring methods.

- Most data in literature refer to arid regions, where during the waiting period more water will evaporate out of the top soil than in humid regions, so that after 2 or 3 days in the upper layer a somewhat higher pF will be obtained.
- The pF-value 2.7, often mentioned in literature, is obtained by centrifuging a moistened sieved soil sample at 1000 g during 40 minutes (measurement of the so-called "moisture equivalent"). The moisture percentage determined in this way seems to correspond with the empirically obtained field capacity. We found however that often there is not yet an equilibrium after 40 minutes centrifuging and therefore the moisture percentages obtained are too high and not corresponding with pF 2.7, but with a lower value.

The wilting point is determined originally by means of sunflowers with three pairs of leaves. If the lowest pair wilts and no recovery occurs as the plant is placed during a 16 hours period in a moist dark room, the moisture percentage of the soil equals the (lower) wilting point. The upper wilting point, which lies 1 to 6 percents of weight lower, is reached if the entire plant is wilting. It appears experimentally that

the pF at the lower wilting point equals about 4.2 and that this point is nearly the same for all crops; it is called briefly wilting point.

Since soils normally are draining to field capacity and plants are wilting at the wilting point, the difference of these moisture percentages is giving the quantity of moisture available for plant growth which a soil can store. It is called *the quantity of available moisture* and is an important soil characteristic in irrigation practice on soils with a deep groundwater level. Besides the distribution of this quantity over the concerning tension range is important.

Table 1 summarizes the moisture percentages at pF 1.9 and 4.2 and their differences for different types of Dutch soils.

TABLE 1. Moisture percentages at pF 1.9 ("field capacity") and 4.2 (wilting point) and available moisture percentages for some Dutch soils

Soil		Moisture percentage by volume at		Available moisture (% by vol.)
		pF 1.9	pF 4.2	
Sandy soils	Sandy soil, poor in humus (from Valkenswaard)	6.6	1.4	5.2
	Sandy soil, medium humous (from Valkenswaard)	29.0	7.7	21.3
	Sandy soil, rich in humus (from Valkenswaard)	45.3	12.3	33.0
	Old arable soil ("esgrond" from Westerwolde)	30.2	7.6	22.6
	Reclaimed peat soil ("dalgrond" from Emmercompascuum)	44.3	14.1	30.2
	Clay holding soils	Light sandy clay soil ("zavel" from Hornhuizen)	33.7	6.4
Marine clay soil (from Reiderwolderpolder)		37.9	24.5	13.4
Old marine clay soil (from Nieuw-Beerta)		43.9	26.3	17.6
Sticky clay soil ("knipklei" from Feerwerd)		37.8	23.2	14.6
Sandy river clay soil ("stroomgrond")		30.7	11.5	19.2
Heavy river clay soil (basin soil from Maaskant)		57.2	34.3	22.9
Loess soil		36.8	8.7	28.1
Peaty soils	Toplayer of peat-moor ("bolster" from Coevorden)	73.7	18.7	55.0
	Wood-peat rich in clay (not desiccated)	60.0	28.2	31.8
	Wood-peat rich in clay (desiccated)	46.1	24.6	21.5

From table 1 we see that the organic matter content has an evident influence (here somewhat over-estimated however) on the available moisture of a sandy soil, that there is still much moisture in clay and peat soils at the wilting point and further that a sandy soil layer with somewhat humus in it often has a higher percentage of available water than a clay layer of the same thickness.

Typical moisture characteristics for sandy soils with and without humus are shown in fig. 12. The latter has the well-known chair-like shape, which is indicating that there is a prevailing pore size as can be expected for well graded sands (see par. 6). It appears from the pF-curves that the sandy soil without humus is already fairly dry at field capacity (point D), that the quantity of available water (EF) is

small and that the pF-range between a wet and a fairly dry soil (here pF 1.6 – 2) is relatively narrow. Therefore such soils are to use for agricultural purposes only if a rather high groundwater-level (say between 100 and 40 cm below surface) can be maintained. The buffer-capacity of the humus holding sandy soil (fig. 12) however is much greater (Cf. available moisture percentage BC with EF of the other soil). This soil can be used agriculturally with a low water table if rainfall is completed by sprinkling irrigation if necessary. It must be pointed out however that at field capacity (point A in fig. 12) the air content is no more than about 7 % by vol., what is too low. Supposing the air percentage must be more than 12, from fig. 12 it follows that the soil must not be held at a pF lower than 2.4.

Fig. 13 is showing the influence of a treatment with Krilium on the shape of the pF-curve of a sandy clay soil. It appears that the pore-space is increased by about 10 vol. %, but that this change must be ascribed to an increase of the cells with greater pores ($> 30 \mu$; see par. 6). The quantity of available moisture is decreased no more than about 3 % by vol. This change of the structure however seems on this soil not to be advantageous in many cases.

In the foregoing the influence of humus on the moisture characteristic was shown. But generally speaking other soil factors as clay content, fineness of the sand fraction, pore space etc. have an influence too. This may be illustrated by the fig.'s 14, 15 and 16, taken from a study of BOEKEL and PEERLKAMP (1957) on marine sandy soils, which are poor in humus. The clay content (fig. 14) appears to have the same influence on the moisture percentages at pF 2.0 and 4.2; both are increasing practical

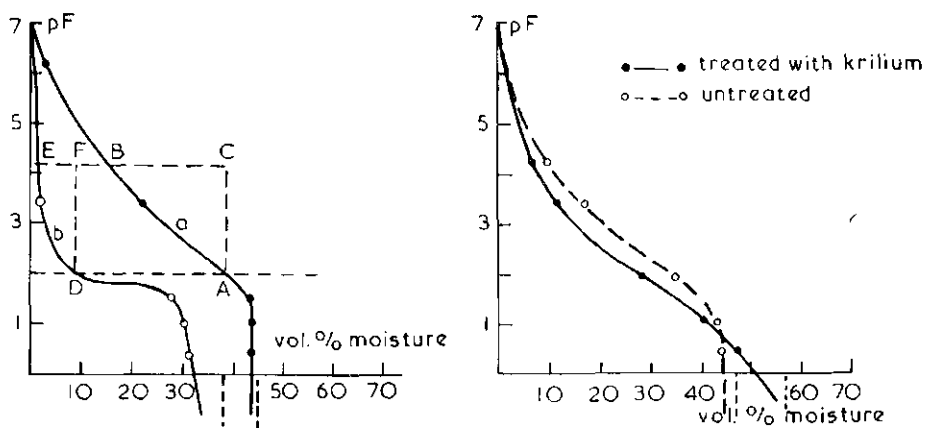


FIG. 12. (left) Moisture characteristics (pF-curves) of a humus holding sandy soil (a) and a sandy soil without humus (b). The pF equals minus infinitely if the soil is saturated with water. Therefore the lower part of the pF-curve is approaching asymptotically the vertical (broken) line through a moisture percentage on the horizontal axis, which equals the pore space. A and D: field capacity. B and E: wilting point. EF and BC: available moisture. FIG. 13. (right) Influence of the soil conditioner Krilium on the pF-curve of a sandy clay soil (from Hornhuizen)

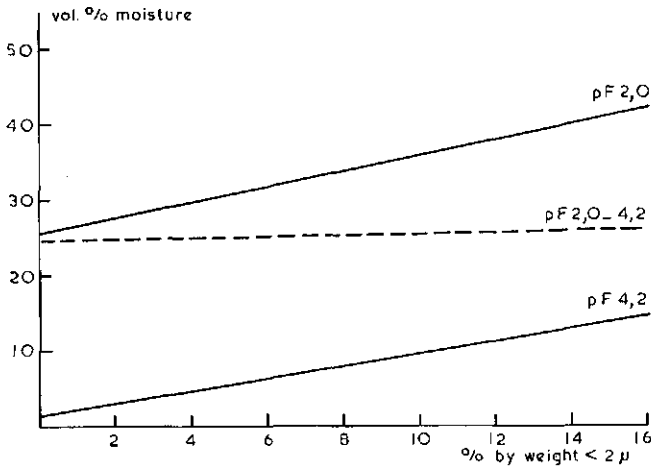


FIG. 14.
Relation between field capacity, wilting point and available moisture on one hand and clay content (fraction < 2 microns) on the other for Dutch marine sandy soils.

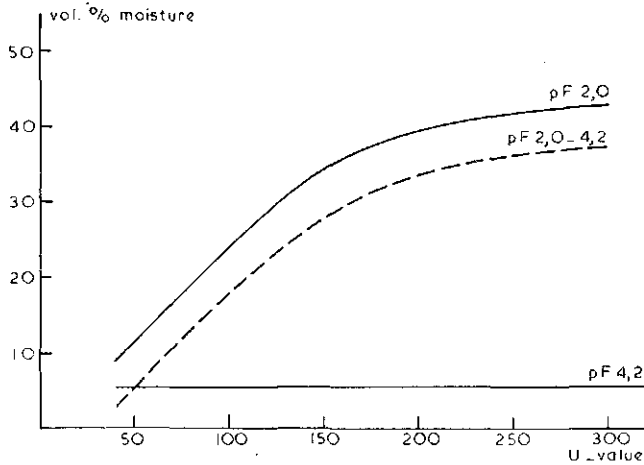


FIG. 15.
Dependence of field capacity, wilting point and available moisture percentage on the fineness of the sand fraction (U-value) for Dutch marine sandy soils.

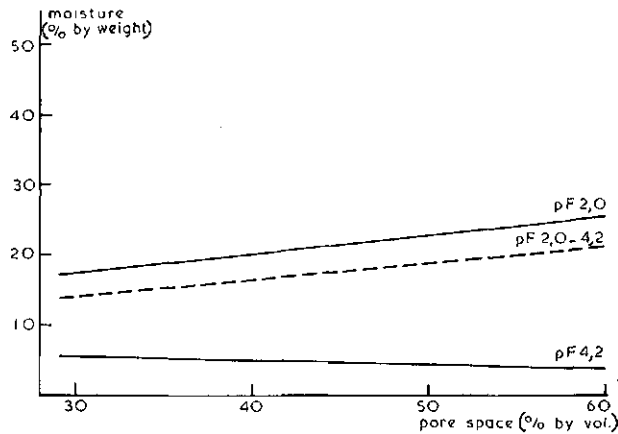


FIG. 16.
Moisture percentages of Dutch marine sandy soils at pF 2.0 and 4.2 and their difference in relation to pore space.

lineary in the same way. Consequently the percentage of available moisture is nearly constant with increasing clay content. The fineness of the sand fraction however, characterized by the so-called U-value (specific surface; HOOGHOUT (1934)), is influencing field capacity, but not the wilting point (fig. 15). Therefore the quantity of available water is increasing with increasing fineness of the sand in the same way as field capacity. Pore space appeared to have an influence too on these soils (fig. 16). The wilting point is decreasing a little, field capacity and available moisture percentage are increasing nearly lineary however if pore space is increasing.

All moisture characteristics mentioned before are determined on drying samples. It appears that if the relation between moisture tension and moisture percentage is determined on moistening samples not the same results are obtained as for drying samples. This effect, which is called *hysteresis* (fig. 17), is due to one or more of the following three factors:

- a. the tension at which a pore space cell is emptied is determined by the size of the greatest pore, which gives entry into the cell; the tension however at which the cell is filled completely is determined by the greatest diameter of the cell, which is greater than that of the greatest pore; therefore a lower tension is necessary in the moistening stage than in the drying one to get the same moisture percentage (reversible hysteresis);
- b. a reorientation of the soil particles in the drying sample (irreversible hysteresis);
- c. soils containing clay and humus are remoistening slowly and often partly after previous drying and
- d. enclosed air, which is dissolving gradually in the soil moisture.

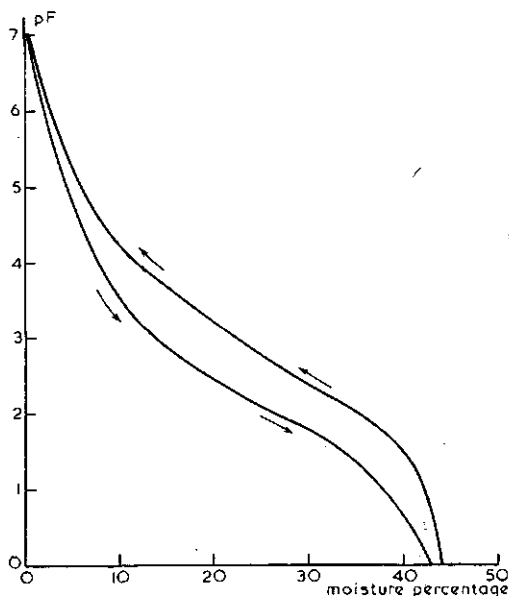


FIG. 17.
Hysteresis of a moisture characteristic (schematically). The arrows are giving the direction in which the moisture state is changing.

Hence there is under field conditions not a sharp relation between moisture tension and moisture percentage as history is unknown and in principle all states between the drying and moistening curve are possible. For practical purposes however it is generally sufficient to work with the drying curve since the difference with the moistening one don't exceed mostly 5% by vol. in undisturbed soils.

6. PRACTICAL APPLICATIONS OF MOISTURE TENSION MEASUREMENTS AND pF-CURVES

The most important applications may be summarized briefly.

a. Measurements of moisture tension in soil in situ

1. To determine the moisture percentage of the soil. Not only the hysteresis is giving uncertainties, but nearly horizontal parts of the pF-curves of well graded sands (cf. fig. 12) too. For several practical purposes applicable however.
2. Determination of moment and quantity of water in sprinkling irrigation. If moisture tension is increased up to pF 3 for instance, a quantity of water, derived from moisture characteristic, must be sprinkled to replenish soil moisture up to field capacity.
3. Moisture movement determinations. The gradient of the moisture tension is determining the driving force; the capillary conductivity is depending on the moisture percentage, thus on moisture tension too (cf. WESSELING (1960) and WIND (1960)).

b. Determination of moisture characteristics of soil samples

1. Determination of field capacity, wilting point and available moisture percentage (see par. 5).
2. Estimation of the change in moisture percentage of a distinct soil layer if the ground water level would be lowered. This was used for instance by one of the authors (PEERLKAMP (1954)) to show that moisture percentage of the soil under a Dutch town, built on wooden piles, should not decrease in consequence of a distinct lowering of the water table so much that the upper ends of the piles would decay.
3. Determination of the pore size distribution to characterize soil structure. From the capillary-rise equation can be computed for each moisture tension (read: height above water table) an effective pore size. Then the pF-scale of the moisture characteristic is to transform into a pore size scale (fig. 11) and for each pore size range can be read the volume occupied by the pores in that range (see f.i.: PEERLKAMP (1948)).

7. SUMMARY

A general survey is given of the statical problems of soil moisture on the base of free energy, moisture potential, moisture tension or pF. Methods to determine the entire pF-curve (sand tank, porous plates, pressure membrane and relative humidity measurements of the room-atmosphere) are described briefly, as well as three methods to measure moisture tension in situ (plaster cup and cone, tensiometer, electrical resistance block). Field capacity and wilting point are introduced as the moisture percentages at pF values of about 2 and 4.2 respectively.

Factors influencing these moisture states and the quantity of available moisture derived from them are discussed. The hysteresis effect and its causes are mentioned. The most important applications of moisture characteristic and moisture potential determinations are summarized briefly.

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