
**Soil quality — Determination of the water-
retention characteristic — Laboratory
methods**

*Qualité du sol — Détermination de la caractéristique de la rétention en
eau — Méthodes de laboratoire*

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 11274 was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 5, *Physical methods*.

Annexes A and B of this International Standard are for information only.

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Introduction

Soil water content and matric pressure are related to each other and determine the water-retention characteristics of a soil. Soil water which is in equilibrium with free water is at zero matric pressure (or suction) and the soil is saturated. As the soil dries, matric pressure decreases (i.e. becomes more negative), and the largest pores empty of water. Progressive decreases in matric pressure will continue to empty finer pores until eventually water is held in only the finest pores. Not only is water removed from soil pores, but the films of water held around soil particles are reduced in thickness. Therefore a decreasing matric pressure is associated with a decreasing soil water content [5], [6]. Laboratory or field measurements of these two parameters can be made and the relationship plotted as a curve, called the soil water-retention characteristic. The relationship extends from saturated soil (approximately 0 kPa) to oven-dry soil (about -10^6 kPa).

The soil water-retention characteristic is different for each soil type. The shape and position of the curve relative to the axes depend on soil properties such as texture, density and hysteresis associated with the wetting and drying history. Individual points on the water-retention characteristic may be determined for specific purposes.

The results obtained using these methods can be used, for example:

- to provide an assessment of the equivalent pore size distribution (e.g. identification of macro- and micropores);
- to determine indices of plant-available water in the soil and to classify soil accordingly (e.g. for irrigation purposes);
- to determine the drainable pore space (e.g. for drainage design, pollution risk assessments);
- to monitor changes in the structure of a soil (caused by e.g. tillage, compaction or addition of organic matter or synthetic soil conditioners);
- to ascertain the relationship between the negative matric pressure and other soil physical properties (e.g. hydraulic conductivity, thermal conductivity);
- to determine water content at specific negative matric pressures (e.g. for microbiological degradation studies);
- to estimate other soil physical properties (e.g. hydraulic conductivity).

Soil quality — Determination of the water-retention characteristic — Laboratory methods

1 Scope

This International Standard specifies laboratory methods for determination of the soil water-retention characteristic.

This International Standard applies only to measurements of the drying or desorption curve.

Four methods are described to cover the complete range of soil water pressures as follows:

- a) method using sand, kaolin or ceramic suction tables for determination of matric pressures from 0 kPa to – 50 kPa;
- b) method using a porous plate and burette apparatus for determination of matric pressures from 0 kPa to – 20 kPa;
- c) method using a pressurized gas and a pressure plate extractor for determination of matric pressures from – 5 kPa to – 1500 kPa;
- d) method using a pressurized gas and pressure membrane cells for determination of matric pressures from – 33 kPa to – 1500 kPa.

Guidelines are given to select the most suitable method in a particular case.

2 Definitions

For the purposes of this International Standard, the following definitions apply.

2.1

soil water-retention characteristic

relation between soil water content and soil matric head of a given soil sample

2.2

matric pressure

amount of work that must be done in order to transport, reversibly and isothermally, an infinitesimal quantity of water, identical in composition to the soil water, from a pool at the elevation and the external gas pressure of the point under consideration, to the soil water at the point under consideration, divided by the volume of water transported

2.3**water content mass ratio** **w**

mass of water evaporating from the soil when dried to constant mass at 105 °C, divided by the dry mass of the soil (i.e. the ratio between the masses of water and solid particles within a soil sample)

2.4**water content volume fraction** **θ**

volume of water evaporating from the soil when dried to constant mass at 105 °C, divided by the original bulk volume of the soil (i.e. the ratio between the volume of liquid water within a soil sample and the total volume including all pore space of that sample)

NOTE 1 The soil water-retention characteristic is identified in the scientific literature by various names including soil water release curve, soil water-retention curve, pF curve and the capillary pressure-saturation curve. Use of these terms is deprecated.

NOTE 2 The pascal is the standard unit of pressure but many other units are still in use. Table A.1 provides conversions for most units.

NOTE 3 Sometimes suction is used instead of pressure to avoid the use of negative signs (see Introduction). However, this term can cause confusion and is deprecated as an expression of the matric pressure.

NOTE 4 For swelling and shrinking soils, seek the advice of a specialist laboratory since interpretation of water-retention data will be affected by these properties.

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3 Guidelines for choice of method

Guidelines are given below to help select the most suitable method in a particular case.

3.1 Sand, kaolin or ceramic suction tables for determination of pressures from 0 kPa to – 50 kPa

The sand, kaolin and ceramic suction table methods are suitable for large numbers of determinations at high pressures on cores or aggregates of different shapes and sizes. Analyses on samples of a wide range of textures and organic matter contents can be carried out simultaneously since equilibration is determined separately for each core. The suction table methods are suitable for a laboratory carrying out analyses on a routine basis and where regular equipment maintenance procedures are implemented.

3.2 Porous plate and burette apparatus for determination of pressures from 0 kPa to – 20 kPa

The porous plate and burette apparatus allows analysis of only one sample at a time, and several sets of equipment are therefore necessary to enable replication and full soil profile characterization. The method is particularly suited to soils with weak structures and sands which are susceptible to slumping or slaking, since minimal sample disturbance occurs. Capillary contact is not broken during the procedure and all samples, particularly soils with higher organic matter content or sandy textures, will equilibrate more rapidly using this technique. This is a simple technique suitable for small laboratories.

3.3 Pressure plate extractor for determination of pressures from – 5 kPa to – 1500 kPa

The pressure plate method can be used for determinations of all pressures to – 1500 kPa. However, different specifications of pressure chambers and ceramic plates are required for the range of pressures, e.g. 0 kPa to 20 kPa, 20 kPa to 100 kPa and 100 kPa to 1500 kPa. The method is, however, best suited to pressures of – 33 kPa or lower, since air entrapment at high negative pressures can occur. It is preferable that soils with similar water-release properties are analysed together to ensure equilibration times are approximately the same, though in practice it may be difficult. Sample size is usually smaller than for the previous two methods and therefore the technique is less suitable for heterogeneous soil horizons, or for those with a strong structural composition. Analysis of disturbed soils is traditionally carried out using this method.

3.4 Pressure membrane cells for determination of pressures from – 33 kPa to – 1500 kPa

The pressure membrane cell should only be used for pressures below – 33 kPa. Capillary contact at higher pressures is not satisfactory for this method. The method is appropriate for all soil types though the use of double membranes is recommended for coarse (sandy) textured soils. Sample size can be selected (according to the size of the pressure cell) to take into account soil structure. Different textures can be equilibrated separately using a suite of cells linked to one pressure source.

4 Sampling

4.1 General requirements

It is essential that undisturbed soil samples are used for measurement at the high matric pressure range 0 kPa to – 100 kPa, since soil structure has a strong influence on water-retention properties. Use either undisturbed cores or, if appropriate, individual peds for low matric pressure methods (< – 100 kPa).

Soil cores shall be taken in a metal or plastic sleeve of a height and diameter such that they are representative of the natural soil variability and structure. The dimensions of samples taken in the field are dependent on the texture and structure of the soil and the test method which is to be used. Table 1 provides guidance on suitable sample sizes for the different methods and soil structure.

Take soil cores carefully to ensure minimal compaction and disturbance to structure, either by hand pressure in suitable material or by using a suitable soil corer. Take a minimum of three representative replicates for each freshly exposed soil horizon or layer; more replicates are required in stoney soils. Record the sampling date, sample grid reference, horizon and sampling depths. Dig out the sleeve carefully with a trowel, trim roughly the two faces of the cylinder with a knife and if necessary adjust the sample within the sleeve before fitting lids to each end, and label the top clearly with the sample grid reference, the direction of the sampling (horizontal or vertical), horizon number and sample depth.

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Wrap the samples (e.g. in plastic bags) to prevent drying. Wrap aggregates (e.g. in aluminium foil or plastic film) to retain structure and prevent drying. Alternatively, excavate blocks measuring approximately 30 cm cube of undisturbed soil in the field, wrap in metal foil, wax (to retain structure and prevent drying) and take to the laboratory for subdivision. Store the samples at 1 °C to 2 °C to reduce water loss and suppress biological activity until they are required for analyses. Treat samples having obvious macrofaunal activity with a suitable biocide, e.g. 0,05 % copper sulfate solution.

Table 1 — Recommended sample sizes (height × diameter) for the different test methods

Dimensions in millimetres

Test method	Structure		
	Coarse	Medium	Fine
Suction table	50 × 100	40 × 76	24 × 50
Porous plate	50 × 76	40 × 76	20 × 36
Pressure plate		10 × 76	10 × 50
Pressure membrane		20 × 76	10 × 50

NOTE 1 The points mentioned here are specific to water-retention analyses. Reference is made to ISO 10381-1 in which general advice on sampling and problems encountered is given.

NOTE 2 In moist conditions, soil is easier to sample and in shrink/swell soils the bulk density under natural conditions is lowest. It is therefore preferable to take samples in the wet season when soil matric pressures are at or near – 5 kPa. Dry conditions should be avoided, especially for clayey soils, which are both difficult to core when dry and contract and swell with varying water content. Samples of swelling and shrinking soils can be taken in cores only under completely saturated conditions, i.e. under the water table and in the full capillary zone. In all other circumstances peds should be taken.

NOTE 3 Other relevant site information should be noted, e.g. soil water status, topsoil/surface conditions, etc. (see clause 5.6).

4.2 Sample preparation

To prepare samples for water-retention measurements at pressures greater than – 50 kPa (see clause 3), trim undisturbed cores flush with the ends of the container and replace one lid with a circle of polyamide (nylon) mesh, similar close-weave material or paper if the water-retention characteristic is known, secured with an elastic band. The mesh will retain the soil sample in the sleeve and enable direct contact with the soil and the porous contact medium. Avoid smearing the surface of clayey soils. Remove any small projecting stones to ensure maximum contact and correct the soil volume if necessary. Replace the other lid to prevent drying of the sample by evaporation. Prepare soil aggregates for high matric pressure measurements by levelling one face and wrapping other faces in aluminium foil to minimize water loss. Disturbed soils should be packed into a sleeve with a mesh attached. Firm the soil by tapping and gentle pressure to obtain a specified bulk density.

Weigh the prepared samples. Ensure that the samples are brought to a pressure of less than the first equilibration point by wetting them, if necessary, by capillary rise, mesh side or levelled face down on a sheet of foam rubber saturated with de-aerated tap water or 0,005 mol/l calcium sulfate solution. Weigh the wet sample when a thin film of water is seen on the surface. This water content represents the total or maximum water-holding capacity and is calculated according to clause 6.5.

Report the temperature at which the water-retention measurements are made.

NOTE 1 It may be necessary to discard samples with large projecting stones. The chemical composition of the wetting fluid can affect the water-retention characteristic, particularly in fine-textured soils with swelling clays. Wetting with distilled or freshly drawn tap water is not generally recommended. De-aerated 0,005 mol/l calcium sulfate solution is suggested to represent the chemical composition of the soil solution.

NOTE 2 The time required for wetting varies with initial soil water content and texture, being a day or two for sands and two weeks or more for clayey soils. Except for sands, wetting needs to be slow to prevent air entrapment in samples. Care should be taken not to leave sandy soils wetting for too long because their structure may collapse. Low-density subsoil sands without the stabilizing influence of organic matter or roots are the most susceptible. The burette method is most suitable for this type of soil and samples can be wetted using the procedure in 6.3. Soils should, ideally, be field-moist when the wetting is commenced; dried soils may cause differences in the water-retention characteristic due to hydrophobia or hysteresis.

General guidelines for wetting times are:

sand	1 to 5 days
loam	5 to 10 days
clay	5 to 14 days or longer
peat	5 to 20 days.

NOTE 3 Increasing temperature causes a decrease in water content at a given pressure. It is recommended that all water-retention measurements be made at a constant temperature of $(20 \pm 2) ^\circ\text{C}$. Where temperature control is not available, the laboratory temperature should be monitored as the work is conducted, and reported in the test report.

NOTE 4 Very coarse pores are not water-filled when the soil sample is saturated by capillary rise.

NOTE 5 Water can be de-aerated by boiling for 5 min. It should be stored cool in a stoppered vessel.

NOTE 6 The water-retention characteristic of swelling and shrinking soils should be determined under the same load as that occurring in the field. Otherwise the laboratory data can deviate from the water-retention characteristic of the soil under natural field conditions.

5 Determination of the soil water characteristic using sand, kaolin and ceramic suction tables

5.1 Principle

A negative matric pressure is applied to coarse silt or very fine sand held in a rigid watertight non-rusting container (a ceramic sink is particularly suitable). Soil samples placed in contact with the surface of the table lose pore water until their matric pressure is equivalent to that of the suction table. Equilibrium status is determined by weighing samples on a regular basis and soil water content by weighing, oven drying and reweighing. The maximum negative pressure which can be applied before air entry occurs is related to the pore size distribution of the packed fine sand or coarse silt which is determined by the particle size distribution, the shape of the particles and their consolidation.

5.2 Apparatus

5.2.1 Large ceramic sink or other watertight, rigid, non-rusting container with outlet in base [dimensions about (50 × 70 × 25) cm] and with close-fitting cover.

5.2.2 Tubing and connecting pieces to construct the draining system for the suction table.

5.2.3 Sand, silt or kaolin, as packing material for the suction table.

Commercially available graded and washed industrial sands with a narrow particle size distribution are most suitable. The particle size distributions of some suitable sand grades and the approximate suctions they can attain are given in table 2. It is permissible to use other packing materials, such as fine glass beads or aluminium oxide powder, if they can achieve the required air entry values.

5.2.4 Levelling bottle, stopcock and 5-litre aspirator bottle.

5.2.5 Tensiometer system (optional). <https://standards.iteh.ai/catalog/standards/sist/7b111e74-0faf-4200-99e9-b1a5f692ccf1/iso-11274-1998>

5.2.6 Drying oven, capable of maintaining a temperature of (105 ± 2) °C.

5.2.7 Balance capable of weighing with an accuracy of 0,1 % of the measured value.

NOTE Examples of a drainage system, sand and kaolin suction tables and details of their construction are described in Annex A.

Table 2 — Examples of sands and silica flour suitable for suction tables

Type	Coarse sand	Medium sand	Fine sand	Silica flour
Use	Base of suction tables	Surface of suction tables (5 kPa matric pressure)	Surface of suction tables (11 kPa matric pressure)	Surface of suction tables (21 kPa matric pressure)
Typical particle size distribution	Percent content			
> 600 µm	1	1	1	0
200 µm to 600 µm	61	8	1	0
100 µm to 200 µm	36	68	11	1
63 µm to 100 µm	1	20	30	9
20 µm to 63 µm	1	3	52	43
< 20 µm	0	0	5	47

5.3 Preparation of suction tables

Prepare suction tables using packing material that can attain the required air entry values (see table 2). In Annex A the detailed procedure for one specific type of suction table is given as an example.

5.4 Procedure

Prepare soil cores as described in 4.2. Weigh the cores and then place them on a suction table at the desired matric pressure. Leave the cores for 7 days. The sample is then weighed, and thereafter weighed as frequently as needed to verify that the daily change in mass of the core is less than 0,02 %. The sample is then regarded as equilibrated and is moved to a suction table of a lower pressure or oven dried. Samples which have not attained equilibrium should be replaced firmly onto the suction table and the table cover replaced to minimize evaporation from the table.

NOTE The time for reaching equilibrium is proportional to the square of the height of the sample but, as a guide, cores normally require at least 7 days to equilibrate at each potential and sometimes 20 days or more. A minimum of 7 days is recommended so that samples establish good capillary connectivity, enabling an equilibrium status to be more rapidly attained.

5.5 Expression of results

5.5.1 Procedure for soils containing less than 20 % stones (diameter greater than 2 mm)

5.5.1.1 Calculate the water content mass ratio at a matric pressure p_m using the formula:

$$w(p_m) = \frac{m(p_m) - m_d}{m_d}$$

where

$w(p_m)$ is the water content mass ratio at a matric pressure p_m , in grams;

$m(p_m)$ is the mass of the soil sample at a matric pressure p_m , in grams;

m_d is the mass of the oven-dried soil sample, in grams.

5.5.1.2 Calculate the water content on volume basis at matric pressure p_m using the formula:

$$\theta(p_m) = \frac{m(p_m) - m_d}{V \times \rho_w}$$

where

$\theta(p_m)$ is the water content volume fraction at a matric pressure p_m , in cubic centimetres water per cubic centimetre soil;

$m(p_m)$ is the mass, in grams of the soil sample at a matric pressure p_m ;

m_d is the mass of the oven-dried soil sample, in grams;

V is the volume of the soil sample, in cubic centimetres;

ρ_w is the density of water, in grams per cubic centimetre (= 1 g cm⁻³).

NOTE 1 If a containing sleeve, mesh and elastic band are used, these should be weighed and their weights deducted from the total weight of the soil core to give $n(p_m)$.

NOTE 2 The water content volume fraction is related to the water content mass ratio as follows:

$$\theta(p_m) = w(p_m) \frac{m_d}{V \times \rho_w} = w(p_m) \frac{\rho_s}{\rho_w}$$

where

$w(p_m)$ is the water content mass ratio at a matric pressure p_m , in grams water per gram soil;

ρ_s is the bulk density of the oven-dried soil, in grams per cubic centimetre.

5.5.2 Conversion of results to a fine earth basis

The stone content of a laboratory soil sample may not accurately represent the field situation and therefore conversion of data to a fine earth basis may be required for comparison of results or for correction to a field-measured stone content. If conversion of results derived from vacuum or suction methods to a fine earth basis (f) is required for soils containing stones, the following method shall be used:

$$\theta_f = \frac{\theta_t}{(1 - \theta_s)}$$

where:

θ_f is the water content of the fine earth, expressed as a fraction of volume;

θ_s is the volume of stones, expressed as a fraction of total core volume;

θ_t is the water content of the total earth, expressed as a fraction of total core volume.

Thus in a soil containing 0,05 total core volume fraction of nonporous stones:

$$\theta_f = \frac{\theta_t}{(1 - 0,05)}$$

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Porous stones retain water and require a different correction. Determine the water content of porous stones at each matric pressure and correct the water content of the soil accordingly; thus in a soil containing 0,05 total core volume fraction of porous stones

$$\theta_f = \frac{\theta_t - (\theta_s \times 0,05)}{0,95}$$

where:

θ_s is the water content of the porous stones, expressed as a fraction of the total porous stone volume in the soil sample.

NOTE 1 In soils containing many very porous stones, it is recommended that the stones be considered as part of the soil mass, and θ_f is not distinguished from θ_t .

NOTE 2 For mixtures of porous and nonporous stones, as in clay soils containing both flint and chalk fragments, correct the total soil value for both stone types.

5.6 Test report

The test report shall include the following information:

- a reference to this International Standard;
- a reference to the method used;
- complete identification of the sample: