

FIELD AND LABORATORY EXERCISES

FOR

A GRADUATE COURSE

IN

SOIL PHYSICS

BY

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1.1. Roughness of boundaries

Apparatus: Relief meter, measuring rod, proforma.

Procedure: Measure height numbers in 0.5 cm at the surface and the bottom of a harrow layer at two places.

Calculations: Roughness of surface, cm

$$R_o = \sqrt{\frac{\sum H_o^2 - \frac{(\sum H_o)^2}{n}}{n-1}}$$

H_o = height numbers, surface
 n = numbers of height measurements

Roughness of the bottom, cm

$$R_b = \sqrt{\frac{\sum H_b^2 - \frac{(\sum H_b)^2}{n}}{n-1}}$$

H_b = height numbers, bottom
 n = numbers of height measurements

1.2. Depth of loose layer

Apparatus and procedure: same as in 1.1.

Calculation: Depth of loose layer, cm

$$H = \frac{\sum H_o - \sum H_b}{n}$$

2. shear strength, vane-shear method

Apparatus: Vane, moment torque wrench, proforma, spade, rubber hammer or small sledge hammer, plastic bags, labels, rubber rings, (balance, drying oven).

Procedure: The vane shear test consists of pushing the vane (a rod with four equally spaced vertical blades on the lower end) into the soil and measuring the torque to rotate it slowly. The soil between the blades tends to turn with the device; this soil shear from the surrounding soil on a cylindrical surface.

Take 10 measurements at a depth of 0-10 cm and 5 measurements at a depth of 10-20 cm in a field and a meadow. Humid samples must be taken from each depth in the field and the meadow.

Calculations: The heighest and lowest values from both measurements should be excluded.

Max turning moment = Shear strength x surface x arm (Kpcm)

$D_{max} = S \times (2\pi hR^2 + 4/3\pi R^3)$ two end surfaces

$D_{max} = S \times (2\pi hR^2 + 2/3\pi R^3)$ one end surface

D_{max} = highest deflection on the moment meter, average of three (eight) measurements, Unit kpcm.

S = shear strength, kp/cm^2 (to be calculated)

h = height of wing, cm

R = radius of wing, cm

Water content can be calculated from the following formula:

$$\text{Watercontent} = \frac{\text{Moist weight} - \text{Dry weight}}{\text{Dry weight}} \times 100\%$$

The weights must be net weights.

3. Pore volume, water volume and air volume

1) Cylinder method

Apparatus: 100 cm³ cylinders with plastic lids, carrying-case, proforma, sampling equipment box, spade, measuring rod, meter scale, (balance, drying oven, airpymometer).

Procedure: Take 5 samples each from 10-15 and 20-25 cm depth in a field and a meadow. Weigh accurately (up to 0.1 g) fresh (field conditions) and oven dried (dried at 105°C for 24 hrs) samples.

Measurement of airvolume is usually carried out by institute people.

Calculations: Water volume = Gross wet weight - Gross dry weight (density of water 1g/cm³), %

Pore volume: Air volume + water volume, %

Material volume: 100 - Porevolume, %

Soil density: $\frac{\text{Net dry weight}}{100}$, g/cm³

Material density: $\frac{\text{Net dry weight}}{\text{Material volume}}$, g/cm³

If airvolume cannot be measured, the pore volume can be calculated by the formula. Pore Volume = (1 - Soil density/ Material density) x 100. Airvolume is calculated as difference between pore volume and water volume.

2) Height method

Apparatus: Profile frame, meter scale, measuring rod, proforma or graphic paper, sledge hammer, piece of plank, spade, bucket, steel yard, plastic bags or paper boxes, (ballance, drying oven).

Procedure: Hammer down the profile frame horizontally into the soil. Measure height numbers at the surface layer. Collect the soil down to the bottom of the plough layer into buckets, and measure height numbers at the bottom layer. Weigh the soil in the buckets, collect 4-5 samples for moisture determination.

The measurements are done at the sampling place in the field for cylinder method. If time permits, measurements can also be carried out for meadow, possibly by dividing the plow layer into a harrow layer and a layer below the harrow layer.

Calculations: Depth of the soil layer:

$$H = \frac{\sum H_o - \sum H_b}{n}$$

H_o = height measured from the surface, cm.

H_b = " " " " bottom, cm

n = numbers of height measurements

Roughness of surface, cm

$$RO = \sqrt{\frac{\sum H_o^2 - \frac{(\sum H_o)^2}{n}}{n-1}}$$

Roughness of the bottom is calculated in the same way.

Volume of the soil layer $V = A \times H$ (cm^3 or liters)

A = Internal area of the frame

Wet soil density $T_v = M_v/v$ (kg/liters or g/cm^3)

M_v = Net Wet weight of soil in the concerned layer

The water^{content}/of samples collected can be calculated as described in exercise 2 and should be averaged.

Dry weight of soil in the profile frame (M)

$$M(1 + \frac{v}{100}) = M_v$$

$$M = \frac{M_v}{1 + \frac{v}{100}}$$

M = net dry weight of soil in the concerned layer

Soil Density of dry soil $T = M/v$ (kg/liters , or g/cm^3)

For calculating the pore volume, material density $2,65 \text{ g/cm}^3$ is used or material density can be measured in laboratory.

Pore volume = $(1 - T/2,65) \times 100, \%$

Water volume = $v \times T, \%$

Air volume = Pore volume - Water volume

4.1. Sampling for drysieving

1. Apparatus

3 plastic buckets, sample splitter, sample scoop, small spade, 2 liters strong paper bags, measuring rod, pencil or ball-point, experimental layout.

2. Time of sampling: The sampling is done after soil tillage operation is finished. Field must be well dried at the time of sampling, otherwise it has no sense for such sampling. Sample collection need to be completed latest by 20th of June.

3. Number of samples: Normally two parallels are taken for each treatment. Nitrogen-fertilization is not normally considered as a treatment here except where it has been used as an improving agent. In such cases, samples are collected from medium N-fertilization treatment.

4. Sampling depth: Samples are collected from 0-5cm layer of the soil. If there is crust on the surface, uppermost layer may be removed before sampling.

5. Procedure: Take 3 plastic buckets and a sample splitter from laboratory. Place two of the plastic buckets as close as possible to each other. Place sample splitter in such a way that cutting in the fibre plate fits in the middle of the two buckets. Two big side plates of the splitter will now stand in a vertical position. By pouring soil over the edge of the inner "triangel", the soil will be divided equally in each bucket.

The third plastic bucket is used for collecting the samples. For sample collection, sample scoop or small spade is used. Mark with the help of a small spade, a square of about 20x20 cm from inside of this square. Remove the soil up to the depth of harrowing. The same applies to rolling experiments. As a general rule, loose layer should be collected. Scoop the soil into the plastic bucket from many sampling squares of one replicate till it is filled. Pour the soil carefully over the top of the splitter. Note: Take care that soil is not lost over the side plates and that it is divided nearly equally into two buckets.

Normally two samples per treatment are sufficient for dry sieving. Therefore, samples from block I and II or from block III and IV can be collected. After collecting and pouring the soil into the buckets from block I, the procedure can be repeated for the same treatment in block II. As stated above, the soil is poured over the splitter so that it is divided nearly equally into two collecting buckets.

One of the collecting buckets is emptied back in the field and thus only half of the original soil volume is left. The splitter is put over the two empty buckets, and the remaining soil is splitted into two halves. Continue this procedure til about 2 liters of the soil is left. Collect the soil into 2 liters strong paper bags.

6. Labelling: Mark the packings properly with all necessary details such as type of experiment, treatment number or block number, depth, time of collection and name of collector.

7. Transportation: Transport soil samples in 2 liters strong paper bags packed in cardboard boxes to the laboratory. If the samples cannot be sent immediately, they have to be placed at a well aerated place with covers opened.

4.2. Dry sieving of soil

Apparatus: Sievs with meshes of 20 mm, 6 mm (0,6 mm), buckets, balance, and spade.

Procedure: Weigh the collected soil samples and sieve them through the biggest sieve first. The soil particles which do not pass through the sieve are weighed. Sieve the rest of the amount of soil through the second sieve and finally through the finest sieve. Weigh the amount left over each sieve.

Calculations: The aggregate size distribution is determined by calculating each fraction as percentage of the total sample. By using 3 sievs, 4 fractions are obtained (in stony soil 5 fractions).

5. Visual judging of soil structure

Apparatus: Spade

Procedure:

1. Dig a small pit. Take out a small block of soil with the help of a spade. The block may be 10 cm thick. Use a small fork or fingers to loosen the soil.
2. Judging features.
 - a. Size of aggregates.
Top points when half or more of the aggregates have size 0.5-5 mm.
 - b. Shape of aggregates.
Rounded and porous aggregates give highest points. Prismatic, or angular and dense aggregates give lowest points.
 - c. Cohesion of aggregates.
Cohesion determined by pressing aggregates between fingers under normal moisture conditions. When aggregates are nearly impossible to crush or they are very easily crushed, few points are given. Middle strong cohesion gives highest points. A middle strong cohesion here means that 1/3 of aggregates have very strong cohesion.
 - d. Porosity.
Rough and porous faces give many points. Smooth and dense faces give few points.
 - e. Porosity of the entire soilblock.
A high porosity gives many points.
 - f. Root development.
Dense and regular rooting give many points.
 - g. Dispersion.
Dispersion gives few points. Open faces give many points.
3. Scale of St number: St 1 - St 10.
St 10 indicates ideal structure for plantgrowth.
4. Time of judging. Early spring or late autumn.

Examples:

Clay or clayey soil. Ploughlayer

St=1 Ploughlayer consists entirely of big blocks with smooth dense faces. Rooting only in cracks.

St=3 Plough layer consists of big and dense aggregates. Smooth cracks with a few visible pores. Rooting mostly between the aggregates.

St=5 Consists mostly of two layers in the plough layer. The upper 7-8 cm thick layer with small and relatively porous aggregates and the lower layer with dense structure.

St=7 The biggest portion of the plough layer consists of porous crumbs. A few dense blocks. Partly some cohesion between the porous aggregates.

St=9 The complete plough layer consists of fine and porous crumbs. Very few dense aggregates.

Sandy soil. Plough layer.

St=1 Single grain structure. No cohesion between the soil particles.

St=3 Very low cohesion between the soil particles and therefore very few aggregates. Example: Loose top layer above a dense "sub"layer.

St=5 Moderate cohesion between the particles. Often a 7-8 cm toplayer of aggregates above a dense "sub"layer.

St=7 Almost the entire plough layer consists of porous aggregates and very few dense aggregates.

Reference. PEERLKAMP, P.K., 1958: A visual method of soil structure evaluation.

Int. Symp. on soil structure, Ghent, May 28-31, 1958.

6. Sample collection by cylinder method

Objective:

To investigate water and air capacity, porosity, density and permeability of soil in natural conditions.

Apparatus:

100 cm³ steel cylinders with one sharp end, plastic lids, driving head, rubber hammer, knife, crowbar, wooden bar. Besides, spade, meter scale, pencil, writing pad, and guidelines for soil description are required. The steel cylinders are packed in special boxes, each containing 36 cylinders.

Procedure:

Dig with the help of a spade to a desired depth. For example, if samples are to be collected from 10-15 cm depth, dig to a 10 cm depth and make a smooth undisturbed surface. Remove plastic lid from cylinder and mount the driving head on the top of the cylinder with the sharpened edge, being on the other end. In low consistency soils, cylinder may be pressed down by hand only, but in high consistency soils cylinder has to be pressed down by hammer. Note! Take care that the upper part of the cylinder is 1/2 cm below the soil surface.

Dig out the soil block containing the cylinder with the help of a spade or a crowbar. Remove surplus soil in order to make the end surfaces smooth. This can be done with the help of a knife in the same way as sharpening a pencil, except that the sharp end will be removed and the end surfaces made smooth. In sticky soils, surplus soil may be removed by sawing with a knife in order to avoid tearing of soil particles. First smoothen one end surface and cover it by plastic lid. Then smoothen the other end and cover it by another plastic lid. Remove the soil outside the cylinder wall. Mark the cylinders with treatment, date of sampling, replication etc. and place them in the transportation boxes.

Remarks:

Number of replicates in a treatment can vary between 3 and 10. In a field experiment with 4 replicates, samples can be collected from each replicate or all parallel samples can be collected within an area of $1/2 \text{ m}^2$ of the same plot. In the last case the samples should be taken from the same replicate for all treatments. In most cases, the first alternative is better but requires more work. The sample plots need to be chosen very carefully. Often there are many wheel trucks over the whole field. Therefore, it should be taken care that the samples should be collected either from outside or from inside of the trucks. First alternative should be preferred

unless something special is mentioned. Sample collection from drains, spots with surplus of fertilizer, hardpans, wet spots etc. should be avoided. A careful choice of a sample plot is as necessary as a careful sampling in itself. If one meets stone or looses a part of the cylinder content, sampling should be repeated. It is always easier to collect samples from a relatively moist soil.

Remember that cylindersamples should always contain 100 cm³ of naturally stored soil.

Transportation of samples:

Send boxes with cylinders and equipment to the laboratory as quick as possible after the sampling is finished. If the samples have to be stored before sending, store them at a cool place.

Survey

Profile number _____ Farm _____ Elevation _____

Date of examination _____ Community _____ Slope gradient _____

Author (s) of description _____ County _____ Slope direction _____

Topography, macro _____ Geological formation _____

Topography, micro _____ Parent material _____

Vegetation _____ Drainage of the profile _____

Precipitation _____ Drainage of the place _____

Temperature _____ Groundwater conditions _____

Horizon	Horizon boundaries	Colour Dry (D) Moist (M) Wet (W)	Texture	Stoniness	Organic matter	Consistence Dry (D) Moist (M) Wet (W)	Structure	Root-development	Mottling	Remark

Soil type _____
Remarks _____

<u>Transition</u>		<u>Shape</u>
Boundaries	Abrupt (<2,5 cm) - a	Smooth - S
	Clear (2.5-6.3cm) - c	Wavy - W (width > height)
	Gradual (6.3-12.5cm) - g	Irregular - I (width < height)
	Diffuse (>12.5cm) - d	Broken - B

<u>Amount</u>	<u>Size</u>	<u>Contrast</u>
colourspot few (<2% of surface) - f	Fine (<5mm) - 1	Faint - F
(mottling) common (2-20% of surface) - c	Medium (5-15mm) - 2	Distinct - D
many (>20% ") - m	Coarse (>15mm) - 3	Prominent - P

<u>Aggregation</u>	<u>Size</u>	<u>Shape and type</u>
Not aggregated - 0	Very fine - vf	Platy - PL
Weakly aggregated - 1	Fine - f	Prismatic (straight top) - PR
Medium aggregated - 2	Medium - m	Cylindrical (Round top) - Cl
Strongly aggregated - 3	Coarse - c	Blocky (Right angled) - BR
	Very coarse - vc	Blocky (Stump angled) - BS
		Cube like - C
		Granular - G
		Single grained - SG
		Massive - M

<u>Wet soil</u>	<u>Moist soil</u>		<u>Dry soil</u>		<u>Cementation</u>
	Non sticky - Wns	Loose - ml - 0	Loose - dl - 0	Weakly cemented - Wc	
Weak sticky - Wws	Very friable - mvf - 1	Very friable - mvf - 1	Soft - ds - 1	Strongly - Sc	
Sticky - Ws	Friable - mf - 2	Friable - mf - 2	Weak hard - dwh - 2	Very strongly cemented - YSc	
Very sticky - Wvs	Firm - mf - 3	Firm - mf - 3	Hard - dh - 3		
	Very firm - mvf - 4	Very firm - mvf - 4	Very hard - dvh - 4		
	Extremely firm - mef - 5	Extremely firm - mef - 5	Extremely hard - deh - 5		

<u>Wet soil</u>	<u>Moist soil</u>	<u>Dry soil</u>	<u>Cementation</u>
Blocks (>20cm) - B	Grained (20-2mm) - G	Fine sand (0.2-0.02mm) - FS	Weakly cemented - Wc
Stone (20-2cm) - S	Coarse sand (2-0,2mm) CS	Silt (.02-0.002mm) S	Strongly - Sc
		Clay (<0.002mm) C	Very strongly cemented - YSc

Profile No.:

Date:

Author:

Mapping Unit:

LUS Capability Class:

Soil Series/Phase:

LUS Code:

Classification:

Location:

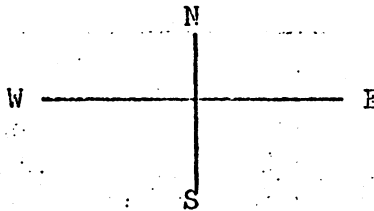
Elevation:

Physiographic position:

S US MS LS B

Slope	< 1%	1-3%	3-5%	5-8%	8-12%	12-25%	> 25%
Slope, convex-concave	F	VGU	GU	U	GR	MR	SR
Slope, uniform	F	VGS	GS	S	MS	MSS	SS

Slope, direction to:



Landform: Plateau/Dissected plateau/Escarpment/Inselberg/Piedmont slope/Terrace/Dissected terrace/Floodplain(Levee/Old levee/Backswamp/cut-off channel)/ Dambo (Vally dambo/ Upland dambo)/Drainage groove/Sinkhole.

Vegetation:	Grassland	Thicket	Tree Savannah	Woodland
Tree species				
Grass species				

Tree cover: O/ Sparse / Light / Medium / Dense

Drainage: V. poor / Poor / Imp. / Mod. well / Well/ S. ex./Ex.

Land Use:

Ground water at depth:

LUS Wetness Class: WO W1 W2 W3

Surface stones: 0-0.0 1% - 0, 1% - 3%-15% - 90% - Rubble

Rock outcrops: 0-5% - 10% - 25% - 50% - 90% - Rock

Laterite: Massive laterite/Laterite rubble/Laterite peas. 2/.....

Erosion: O/Moderate/Severe - Water/wind

Salt or Alkali: C/Slightly /Moderate/Strongly

Termite mounds: Average base diameter height distance

" " Colour Other biotic influence:

Nature of limiting horizon:

Parent material:

Horizon Designation					
Depth, cm					
Colour Dry					
" Moist					
Mottles	Fe Com M Fi Med C Fa Di Pr	Fe Com M Fi Med C Fa Di Pr	Fe Com M Fi Med C Fa Di Pr	Fe Com M Fi Med C Fa Di Pr	Fe Com M Fi Med C Fa Di Pr
Mottles, Colour					
Rusty Root Channels	O Wk M S	O Wk M S	O Wk M S	O Wk M S	O Wk M S
Texture	S-LS-SL-SCL SC-L-CL-C	S-LS-SL-SCL SC-L-CL-C	S-LS-SL-SCL SC-L-CL-C	S-LS-SL-SCL SC-L-CL-C	S-LS-SL-SCL SC-L-CL-C
Organic matter	O T S	O T S	O T S	O T S	O T S
Structure	M Abk Pl Cr Sbk B Pr W O Wk M S F Med C	M Abk Pl Cr Sbk B Pr W O Wk M S F Med C	M Abk Pl Cr Sbk B Pr W O Wk M S F Med C	M Abk Pl Cr Sbk B Pr W O Wk M S F Med C	M Abk Pl Cr Sbk B Pr W O Wk M S F Med C
Structure, org. hor.					
Consistency	Dry	LSH	LSH	LSH	LSH
	Moist	Sl V Ext L Fr Fi Sl V Ext	Sl V Ext L Fr Fi Sl V Ext	Sl V Ext L Fr Fi Sl V Ext	Sl V Ext L Fr Fi Sl V Ext
	Plasticity	O Sl Pl V	O Sl Pl V	O Sl Pl V	O Sl Pl V
Wet	Stickiness	O Sl St V	O Sl St V	O Sl St V	O Sl St V
Moisture	D JM M W	D JM M W	D JM M W	D JM M W	D JM M W
Cutans	O Pa Br Co Th Mod Thk	O Pa Br Co Th Mod Thk	O Pa Br Co Th Mod Thk	O Pa Br Co Th Mod Thk	O Pa Br Co Th Mod Thk
Cementation	Wk S In	Wk S In	Wk S In	Wk S In	Wk S In
Pores	O F C M Mi V F M C	O F C M Mi V F M C	O F C M Mi V F M C	O F C M Mi V F M C	O F C M Mi V F M C
Permeability	Sl Mod Ra	Sl Mod Ra	Sl Mod Ra	Sl Mod Ra	Sl Mod Ra
Roots	F Med C F C M	F Med C F C M	F Med C F C M	F Med C F C M	F Med C F C M
Rock Fragments	FG CG S B	FG CG S B	FG CG S B	FG CG S B	FG CG S B
Concretions	Fe Mn Fe-Mn Ca	Fe Mn Fe-Mn Ca	Fe Mn Fe-Mn Ca	Fe Mn Fe-Mn Ca	Fe Mn Fe-Mn Ca
Crystals/Stains	Gyp Ca Mn Si Salt	Gyp Ca Mn Si Salt	Gyp Ca Mn Si Salt	Gyp Ca Mn Si Salt	Gyp Ca Mn Si Salt
Boundary	Ab Cl Gr D Sm Wa I Br	Ab Cl Gr D Sm Wa I Br	Ab Cl Gr D Sm Wa I Br	Ab Cl Gr D Sm Wa I Br	Ab Cl Gr D Sm Wa I Br
Remarks					

8. Undecomposed organic matter in soil (roots)Principle

Soil samples of known volumes are collected from each depth. The soil samples are suspended in water and the soil suspension is washed through a couple of sieves. This treatment is repeated until only sand and clean water is left. The amount of organic matter is determined by ignition.

Apparatus:

Straight spade, broad knife, measuring rod, sample bags, washing tube, plastic bucket, sieve 0.5 mm, sieve 2 mm, stirring rod, waterbasin, drying oven, heating furnace, tweezers, weighing beaker, balance (sensitive to 0.01 g), balance for loss on ignition (sensitive to 0.001 g).

Procedure:

Harvest all vegetation down to the surface at the sampling spot. Dig profile with a straight wall with the help of a spade. Cut out with the help of a broad knife known soil volume, for, example, 20cm x 20cm x 20cm. Collect the soil in a proper bag with sampling place, treatment, depth, time of sampling, and size of sample. The soil should be moist under collection. Making soil suspension and washing can be best done in a water-basin in a laboratory. Put the samples in big plastic buckets. Wash the sample with water under occasional stirring till the bucket is full. Roots and parts of straw etc. will float.

Decant the suspension over a double sieve, the upper one with 2 mm meshes and the lower one with 0.5 mm. Washing, stirring, and decanting should continue until only clean water and gravel are left in the bucket and no visible organic matter floats up.

Wash the material on the sieves with water. Fine particles will pass through and only organic material will be left. The sieve with big meshes should be dried in order to make organic matter handling easier.

Wash the whole material on the sieve with the fine meshes into a bucket and repeat the process of washing and stirring. Parts of the soil will precipitate. Decant water with floating organic remnants over to the sieve with the finer meshes.

Remove organic matter by hand from the sieve to a special drying beaker and dry it at 105°C for overnight before weighing.

Put the material from the sieve with bigger meshes on a clean table, sort out by hand, parts of straw, stones, gravels and parts of plants. This work can be simplified by using a wide sieve. Remove with help of a tweezer underground stems of couch grass and sowthistle and dry them at 105°C overnight before weighing.

There are 3 fractions viz. underground stems, big roots and fine material. The fine material contains also seeds of weeds, especially from the top soil.

At the end weigh the samples from each fraction for ignition. The samples are ignited at 500°C during the night and weighed again.

Calculations

Results can be calculated for a desired depth on a decare or hectare basis.

Example for one fraction and one depth:

Horizontal sampling surface is: 20cm x 20cm = 400 cm² = 0.04 m².

Dry weight		T (D)
	before ignition	GF (--B)
	after "	GE (--A)

Loss on ignition $G = \frac{GF - GE}{GF} \times 100\%$

Undecomposed organic material per decare: OM

$$OM = \frac{T \times G \times 1000}{100 \times 0.04} = 250 \times T \times G$$

Each fraction is summed up from all depths in a profile. Similarly, big roots, fine material, and all the three fractions are summed up over all depths. The total sum thus, is an expression for the amount of undecomposed organic material per decare for the profile concerned.

9. Measurement of conductivity of water (above ground water level) in field.

Permeameter method

Principle:

It is based upon vertical downward flow of current from a reservoir which keeps water level in a cylinder constant. An inner cylinder, where the conductivity is measured, is surrounded by an outer cylinder, and the water level in this cylinder is kept at the same level as in the inner cylinder. Hydraulic height at the outlet of the cylinder is measured with a tensiometer. When there is atmospheric pressure at the outlet, there is a stationary current flow for a constant waterheight inside the cylinder, and Darcy's law can be applied.

Apparatus:

1. Main water tank of about 50 litres capacity (plastic) with a glasstube on the outside.
2. Platform to keep the maintank above the ground.
3. Cylinder of about 30 cm height with sharpened lower end and strengthened upper end.
4. Floating valve, eventually a carburettor float.
5. Rubber tube to connect tank and float.
6. Outer cylinder with a diameter of about 2-3 times of the inner cylinder.
7. Rod to keep the float on place.
8. 4 tensionmeters, preferable with mercury.
9. Driving head and sledge for cylinder.
10. Spade.
11. Spirit level.
12. An extra tank of approximately 100 liters.

Procedure:

Place cylinders either at the surface or at a desired depth. If the cylinders are placed at a desired depth, dig a sufficient opening to get the cylinders down. Hammer down the cylinders to approximately 10 cm depth and place them concentric. Fill the inner cylinder with a thin layer of sand. Place four tensionmeters in between the outer and the inner ring at a depth just above 10 cm. Mount float, rubber tube, and tank. Open the crane on the tank. This will fill the inner cylinder with water. At the same time fill the outer cylinder to the same height.

Note down time and volume of water which has streamed through the soil in the inner cylinder. When the tensiometers show 0 suction or speed of water current through the soil is constant, the observations for time and volume are collected. These measurements are used for calculating the hydraulic conductivity.

Calculations:

$$\frac{Q}{AT} = k \times \frac{H}{L}$$

$$k = \frac{Q}{AT} \times \frac{L}{H}$$

k = Hydraulic conductivity cm/hour or cm/minute

Q = Volume of water flow (cm³) in time t (minutes or hours).

A = Area of inner cylinder, cross-section in cm²

L = Length of cylinder below the soil surface.

H = Distance from the bottom of the inner cylinder to the water level.

Comments:

Water level may be 15 to 20 cm above the bottom of the cylinder, or approximately 5-10 cm above the ground level. Note that H has to be measured from lower end of the cylinder to the water level.

10. Pipette and hydrometer methods. Mechanical analysis.

I. Apparatus:

A. Common apparatus

Warming plate

Drying oven

1000 ml measuring cylinders

Automatic pipettes, 5 ml, 25 ml

Magnetic stirrer

Dispersion machine with dispersion beakers

Stiring rod

Stop watch

Wash bottle

2000 ml beakers

2500 ml bottle with screw cap

100 ml beakers

600 ml beakers

Ballance, sensitive up to 0.1 g

100 ml graduated cylinders

Tables for calculating grainsizes

Glass rod

Sievs with 0.6 mm, 0.2 mm, and 0.06 mm meshes.

Suction apparatus, bended glass tubes and bottle with 3 openings.

B. Special apparatus

1. For pipette method.

Ballance sensitive up to 1 mg

Pipette 20 ml

Table for time of depth measurements

2. For hydrometer method

Hydrometer ASTM 152 H, graded in g/litres, or KELAB, graded in g/litres.

Table for calculation of grainsize

II. Reagents:

35% hydrogen peroxide (H_2O_2)

1 N HCL (86 ml concentrated HCl/liter)

Acetic acid (96%)

0.05 M Sodium pyrophosphate ($Na_4P_2O_7 \cdot 10 H_2O$) 22.3 g/litre

1 N Mg-chloride ($MgCl_2 \cdot 6 H_2O$) 203 g/litres

Amylcohol

III. Weighing

Soil samples containing 10 and 50 g of dry matter are used for pipette and hydrometer methods, respectively.

Weigh about 12 and 60 g of soil in 600 or 800 ml beakers and mark them accordingly before putting them for drying at 105°C for overnight. Take 10 and 50 g of dried samples for oxidation.

IV. Dispersion

Put the beakers with the samples on a warm cooking plate under a ventilation hood.

1. Add 5 ml of acetic acid (reduction of high valence Mn).
2. Add 10 ml of N hydrochloric acid (acidic reaction, removal of carbonates).
3. Stir for a while.
4. Add 25 ml of hydrogen peroxide (10 ml for pipette method) under stirring with a glass rod for removal of organic matter.
5. If hard frothing, add some drops of amylalcohol.
6. Continue with a new sample til all the samples have got the same amount of hydrogen peroxide. Then the first "round" is finished.
7. Add new doses of hydrogen peroxide until a sample stops frothing or froths as a humusfree sample.
8. Remove samples from the cooking plate after the treatment with the hydrogen peroxide is finished.
9. Wash all soil particles on inside walls of the beakers.
10. Add 25 ml of 1 N hydrochloric acid under stirring.
11. Stir for a while.
12. Fill the beaker with distilled water up to 2 cm from its upper rim.
13. Stir it for approximately 1 minute.
14. Add some drops of Mg-chloride. Let it stand til the liquid above the sediment becomes clear.
15. Suck away the liquid above the sediment with the help of a bended glass rod connected to vacuum.
16. Repeat operation 12.15.
17. Add 100 ml of sodium pyrophosphate solution.
18. Add approximately 300 ml of distilled water.

19. Stir and let it stand for approximately 10 minutes.
20. Transfer the soil suspension into the dispersion beaker by washing with distilled water.
21. Disperse the suspension for 5 minutes on a dispersion machine.
22. Transfer the content into a 1000 ml cylinder by washing with distilled water.
23. Fill the cylinder up to the mark with distilled water (Note: Remember to mark the cylinders).
24. Make a blank with 100 ml sodium pyrophosphate solution and 900 ml distilled water. Add 3-5 drops of amylalcohol to blank if hydrometer is to be used.

Remarks:

Hydrogen peroxide for oxidation of organic matter are needed approximately in the following amounts:

Content of organic matter	<3%	3-10%	10-20%
ml H ₂ O ₂ , 30%, for 10 g sample	10	20	30
" " " " 50 g "	50	100	150

Normally more is required because some of it boiles away without reacting with organic matter.

Use distilled water with a temperature of 20°C.

V. Sedimentation analysis

A. Pipette method

Stir the soil suspension with a rod. Close the opening of the cylinder with one hand. Turn the cylinder upside down several times until the suspension is homogenous. Place the cylinder on the desk and start the stop watch.

1. Take the first sample at 15 cm depth (60 μm) by sucking away with pipette between 2 seconds before and 2 seconds after the time given in Table 1.

2. Take the second sample at 4 cm depth (20 μm) using the same procedure as in 1.
3. Take the third sample at 4 cm depth (6 μm) using the same procedure as in 1.
4. Take the fourth sample at 4 cm depth (2 μm) using the same procedure as in 1.
5. Take one sample from the blank.
6. Weigh the samples after drying at 105°C in weighing beakers. Correct for tara and blank. Calculate the concentration in percent using the following formulas:

$$K_1 = D - T_1$$

K_1 = mass of soil (in pipetted solution)

D = mass of soil + tara

T_1 = tara

$$K_2 = E - T_2$$

K_2 = mass of matter in blank (in pipetted solution)

E = mass of matter in blank + tara

T_2 = tara

$$\underline{K} = K_1 - K_2$$

\underline{K} = mass of soil, corrected for blank (in pipetted solution)

$$\underline{P} = \frac{K \times 1000 \times 100}{X \times 20}$$

\underline{P} = Sum per cent

X = mass of the original sample

B. The hydrometer method

Stir soil suspension hard with a rod. Close the opening of the cylinder with one hand. Turn the cylinder upside down several times until the suspension is homogenous. Place the cylinder on the desk and start the stop watch.

1. Lower the hydrometer carefully into the suspension. If there is foam, add some drops of amylalcohol.

Read the scale on the hydrometer along the upper liquid contact after $\frac{1}{2}$, 1, 2 and 5 minutes. Note down the readings. After 2 minutes, rinse the hydrometer. Use an extra container for rinsing. Repeat the procedure with other cylinders. Also note down corresponding readings from the blank.

2. Stir all the samples. Take readings after 10, 20, 50, 100, 200 and 400 (if possible) minutes, and also after 24 hrs.

Calculations:

$$C = A - B$$

C = concentration of soil, g/litre

A = hydrometer reading g/litre

B = blank reading g/litre

$$P = \frac{C \times 100}{X}$$

X = mass of the original sample

P = sum per cent

Grainsize, \underline{d} , is read from Table 2 by using the reading \underline{A} and the time.

VI. Sieving analysis

Sieve soil suspension after the sedimentation analysis through 0,6 mm, 0,2 mm, 0,06 mm sieves (wet sieving) and collect the different fractions in 100 ml beakers. Dry them over night at 105^oC and weigh them. Remember to mark the beakers with number, fraction, tara.

Calculations:

$$K3 = F - T3$$

K3 = mass of sand

F = mass of sand+tara

T3 = tara

$$P = \frac{K3 \times 100}{X}$$

X = mass of the original sample

In samples with only traces of sand, only 0,06 mm sieve may be used. Similarly, other fractions can also be calculated.

VII. Drawing of sumation curves and calculation of the fractions

A. Correction for organic matter.

Organic matter determination is carried out parallel with the sedimentation analysis. The ash and mineral contents in the sample are calculated as follows.

The ash content

$$a = 100 - h$$

a = ash content, %

h = organic matter content, %

The mineral content.

$$m = \frac{X \times a}{100}$$

X = size of dry sample

m = mineral content, g.

a = ash content, %

All percents of the sums need to be corrected:

$$P_k = \frac{C \times 100}{m}$$

P_k = corrected per cent of the sum.

The same applies to all the sand fractions.

$$P_k = \frac{K3 \times 100}{m}$$

P_k = corrected per cent of the fraction.

NB! This will be correct only when all organic matter is oxidized.

B. Drawing of diagram for the summation curve

Plot summation curve by using the particle size numbers and the corrected sums of the percent. If the curves from the sieving and the sedimentation do not coincide around 60 μm, they need to be reviewed critically before a new correction. In hydrometer method, one should not trust too much on two first readings. If the coincidence is relatively good, plot a soft curve from the last point on the sieving curve to the next natural point on the sedimentation curve (third reading on the hydrometer).

If there is a big distance between the sieving and the sedimentation curves at 60 μm, the experiment should be repeated after removing the iron hydroxides. Method mentioned in the appendix I can be used for this purpose. The simplest way of correcting is as follows:

No correction is done for organic matter. All the fractions are summed up. Let us call the sum s. Multiply all fractions with X/s, and the total sum will then be equal to X (or 100 per cent). X is for example, 50 g or 10 g. A more elaborate but also more accurate way is as follows:

By considering the amount of dry matter, loss on ignition, 1000 minutes reading ("clay content"), the mineral content in the sample may be estimated. It has, however, to be taken in consideration that the oxidation is incomplete. When organic matter content is <3% all can be considered as oxidized. When the content is 3-6%, approximate by 70-80% is oxidized, and with higher amount of organic matter, the oxidized part may drop to 50%. The oxidized fraction can drop further if organic matter is more than 15-20%. Example: Suppose the first result shows 47 g in the sample after the readings. Then a sample plotting is done by using the correction factor 50/47, and a new factor is calculated by comparing the sample plotting with $\frac{1}{2}$ minute reading and the sum of the sand fractions.

References

1. DAY, P.R. 1956. Report of the Committee on Physical Analyses (1954-55). Soil Sci. Soc. Amer. Proc. 20:167.
2. DAY, P.R. 1965. Particle fractionation and particle size analysis. Method of Soil Analysis Par. I, ASA Monograph. 10.9. 545-567.
3. GANDHAL, R. 1952. Hydrometemetoden. Geol. Fören., Förhandl. Bd. 74, H. 4:497.
4. ELONEN, P. 1971. Particle analysis of soil. Suomen maataloustietullisen seuran julkaisuja. 122, 1-122 (Hämeenlinna 1971).

Appendix 1.

Removal of ironhydroxides

Reagents:

Sodium citrate dihydrate 0.3 M, 88g/l litre

Sodium bicarbonate, 1 N 84 "

Sodiumdithionite, solid

Sodium chloride solution, saturated

Aceton.

Procedure.

After oxidation, add approximately 100 ml sodium citrate solution, 10 ml sodium bicarbonate, and 100 ml distilled water. Warm to approximately 80°C in a water-bath. Add 1 g solid sodium dithionite. Stir 5-10 minutes. Add 30 ml sodium chloride solution. If the water at the top is not clear, add 20 ml aceton. (Note! The water must not be warmer than 80°C.) Now the water can be decantated, and the sample should not be dried before further treatment.

Appendix 2.

Acetate method for removal of carbonates and soluble salts.

Reagents:

Sodium acetate, 1 N (102 g/litre)

Procedure.

Carbonates and soluble salts are normally removed before H₂O₂ treatment.

After weighing 60g (12g) soil in a 600 ml beaker, add approximately 300 ml sodium acetate. Stir thoroughly and warm carefully on a cooking plate. When it starts boiling, remove the beaker and add some drops of magnesium chloride. Water is carefully decantated. Add 300 ml sodium acetate once more and repeat the procedure. The samples are ready for oxidation.

Tabell 1. Sedimentation time and measuring depth in relation to temperature. for pipette method.

Temperature °C	Viscosity		Sedimentation time			
	centi- poises	60 μ m (15 cm)	20 μ m (4 cm)	6 μ m (4 cm)	2 μ m (4 cm)	
15.....	1.14	53 sek	2 min 07 sek	23 min 30 sek	3 t	31 min
16.....	1.11	51	2 03	22 50	3	26
17.....	1.08	50	2 00	22 20	3	20
18.....	1.05	49	1 57	21 40	3	15
19.....	1.03	48	1 54	21 10	3	11
20.....	1.00	46	1 51	20 40	3	06
21.....	0.98	45	1 49	20 10	3	01
22.....	0.95	44	1 46	19 40	2	57
23.....	0.93	43	1 44	19 10	2	53
24.....	0.91	42	1 41	18 50	2	49
25.....	0.89	41	1 39	18 20	2	45
26.....	0.87	40	1 37	18 00	2	41
27.....	0.85	39	1 35	17 30	2	38
28.....	0.83	39	1 33	17 10	2	34
29.....	0.81	38	1 31	16 50	2	31
30.....	0.80	37	1 29	16 30	2	28

Tabell 2.

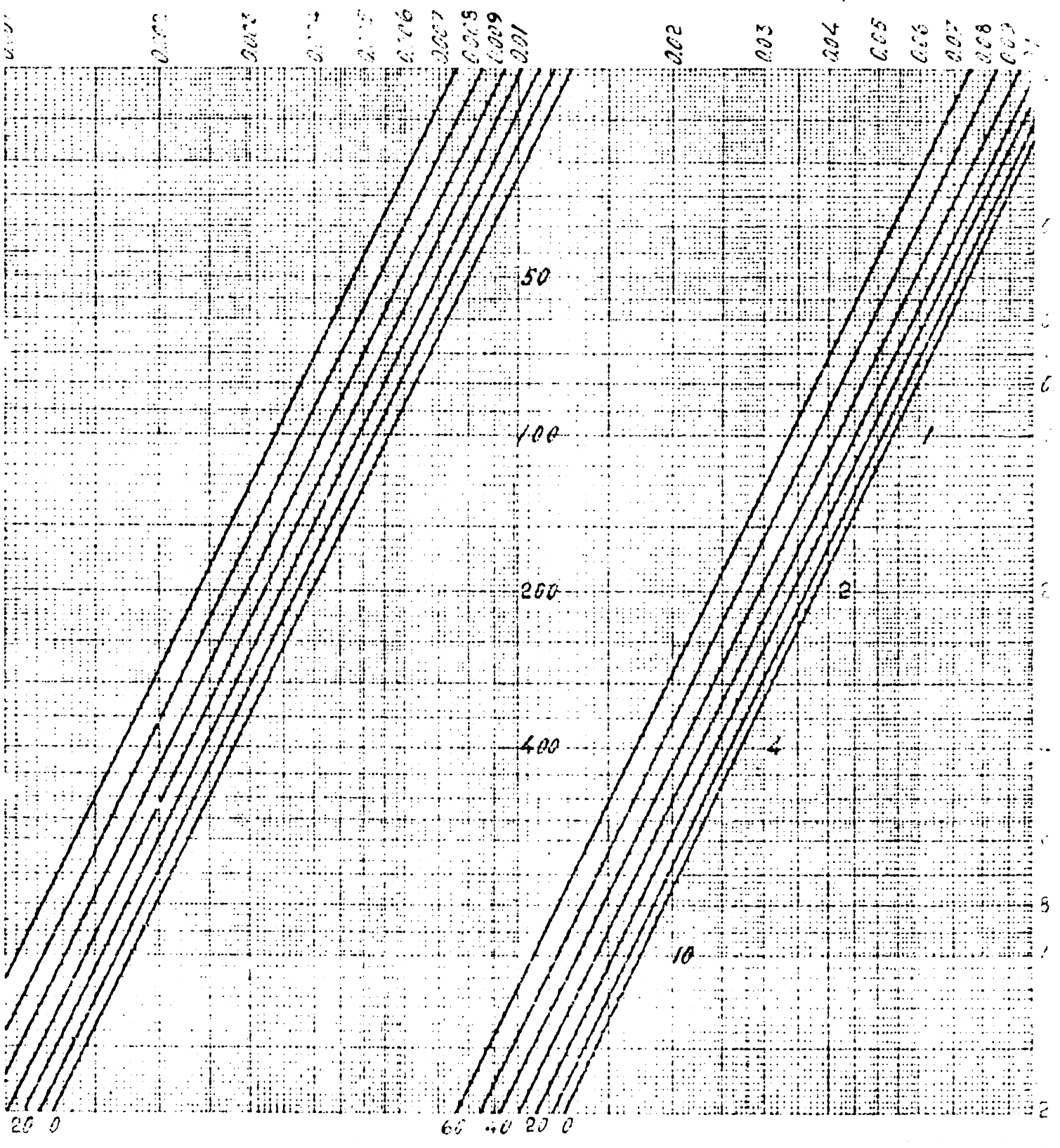
Grain size in mikrons for given hydrometer readings (g/l) and settling time (min.).

Settling time (minutes)

g/l	1	1	1	2	5	10	20	50	100	200	400	800	1000	1200	1400													
1	77	6	54	9	38	8	24	6	17	4	12	3	7	8	5	5	3	9	2	7	1	9	1	7	1	6	1	5
2	77	2	54	6	38	6	24	4	17	3	12	2	7	7	5	5	3	9	2	7	1	9	1	7	1	6	1	5
3	76	8	54	3	38	4	24	3	17	2	12	1	7	7	5	4	3	8	2	7	1	9	1	7	1	6	1	4
4	76	5	54	1	38	3	24	2	17	1	12	1	7	7	5	4	3	8	2	7	1	9	1	7	1	6	1	4
5	76	1	53	8	38	0	24	1	17	0	12	0	7	6	5	4	3	3	2	7	1	9	1	7	1	6	1	4
6	75	7	53	5	37	8	23	9	16	9	12	0	7	6	5	4	3	8	2	7	1	9	1	7	1	5	1	4
7	75	2	53	2	37	6	23	8	16	8	11	9	7	5	5	3	3	8	2	7	1	9	1	7	1	5	1	4
8	74	7	52	8	37	3	23	6	16	7	11	8	7	5	5	3	3	7	2	6	1	9	1	7	1	5	1	4
9	74	4	52	6	37	2	23	5	16	6	11	8	7	4	5	3	3	7	2	6	1	9	1	7	1	5	1	4
10	74	0	52	3	37	0	23	4	16	5	11	7	7	4	5	2	3	7	2	6	1	8	1	7	1	5	1	4
11	73	5	52	0	36	8	23	3	16	4	11	6	7	4	5	2	3	7	2	6	1	8	1	6	1	5	1	4
12	73	1	51	7	36	6	23	1	16	3	11	6	7	3	5	2	3	7	2	6	1	8	1	6	1	5	1	4
13	72	8	51	5	36	4	23	0	16	3	11	5	7	3	5	2	3	6	2	6	1	8	1	6	1	5	1	4
14	72	3	51	1	36	1	22	9	16	2	11	4	7	2	5	1	3	6	2	6	1	8	1	6	1	5	1	4
15	71	8	50	8	35	9	22	7	16	1	11	4	7	2	5	1	3	6	2	5	1	8	1	6	1	5	1	4
16	71	4	50	5	35	7	22	6	16	0	11	3	7	1	5	1	3	6	2	5	1	8	1	6	1	5	1	3
17	70	9	50	1	35	4	22	4	15	8	11	2	7	1	5	0	3	5	2	5	1	8	1	6	1	4	1	3
18	70	4	49	8	35	2	22	3	15	7	11	1	7	0	5	0	3	5	2	5	1	8	1	6	1	4	1	3
19	70	0	49	5	35	0	22	1	15	7	11	1	7	0	5	0	3	5	2	5	1	8	1	6	1	4	1	3
20	69	7	49	3	34	9	22	0	15	6	11	0	7	0	4	9	3	5	2	5	1	7	1	6	1	4	1	3
21	69	3	49	0	34	6	21	9	15	5	11	0	6	9	4	9	3	5	2	5	1	7	1	5	1	4	1	3
22	68	7	48	6	34	4	21	7	15	4	10	9	6	9	4	9	3	4	2	4	1	7	1	5	1	4	1	3
23	68	3	48	3	34	2	21	6	15	3	10	8	6	8	4	8	3	4	2	4	1	7	1	5	1	4	1	3
24	67	9	48	0	33	9	21	5	15	2	10	7	6	8	4	8	3	4	2	4	1	7	1	5	1	4	1	3
25	67	3	47	6	33	7	21	3	15	1	10	6	6	7	4	8	3	4	2	4	1	7	1	5	1	4	1	3
26	67	0	47	4	33	5	21	2	15	0	10	6	6	7	4	7	3	4	2	4	1	7	1	5	1	4	1	3
27	66	6	47	1	33	3	21	1	14	9	10	5	6	7	4	7	3	3	2	4	1	7	1	5	1	4	1	3
28	65	0	46	7	33	0	20	9	14	8	10	4	6	6	4	7	3	3	2	3	1	7	1	5	1	3	1	2
29	65	6	46	4	32	8	20	8	14	7	10	4	6	6	4	6	3	3	2	3	1	6	1	5	1	3	1	2
30	65	2	46	1	32	6	20	6	14	6	10	3	6	5	4	6	3	3	2	3	1	6	1	5	1	3	1	2
31	64	6	45	7	32	3	20	4	14	5	10	2	6	5	4	6	3	2	2	3	1	6	1	4	1	3	1	2
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33	63	6	45	0	31	8	20	1	14	2	10	1	6	4	4	5	3	2	2	3	1	6	1	4	1	3	1	2
34	63	1	44	6	31	5	19	9	14	1	10	0	6	3	4	5	3	2	2	2	1	6	1	4	1	3	1	2
35	62	8	44	4	31	4	19	9	14	0	9	9	6	3	4	4	3	1	2	2	1	6	1	4	1	3	1	2
36	62	2	44	0	31	1	19	7	13	9	9	8	6	2	4	4	3	1	2	2	1	6	1	4	1	3	1	2
37	61	5	43	5	30	8	19	5	13	8	9	7	6	2	4	4	3	1	2	2	1	5	1	4	1	3	1	2
38	61	2	43	3	30	6	19	4	13	7	9	7	6	1	4	3	3	1	2	2	1	5	1	4	1	2	1	2
39	60	8	43	0	30	4	19	2	13	6	9	6	6	1	4	3	3	0	2	2	1	5	1	4	1	2	1	1
40	60	2	42	6	30	1	19	1	13	5	9	5	6	0	4	3	3	0	2	1	1	5	1	3	1	2	1	1
41	59	8	42	3	29	9	18	9	13	4	9	5	6	0	4	2	3	0	2	1	1	5	1	3	1	2	1	1
42	59	3	41	9	29	6	18	7	13	3	9	4	5	9	4	2	3	0	2	1	1	5	1	3	1	2	1	1
43	58	7	41	5	29	3	18	6	13	1	9	3	5	9	4	2	2	9	2	1	1	5	1	3	1	2	1	1
44	58	3	41	2	29	1	18	4	13	0	9	2	5	3	4	1	2	9	2	1	1	5	1	3	1	2	1	1
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46	57	1	40	4	28	6	18	1	12	8	9	0	5	7	4	0	2	9	2	0	1	4	1	3	1	2	1	1
47	56	6	40	0	28	3	17	9	12	6	9	9	5	7	4	0	2	8	2	0	1	4	1	3	1	2	1	1
48	56	0	39	6	28	0	17	7	12	5	8	9	5	6	4	0	2	8	2	0	1	4	1	3	1	1	1	1
49	55	6	39	3	27	8	17	6	12	4	8	8	5	6	3	9	2	8	2	0	1	4	1	2	1	1	1	1
50	55	0	38	9	27	5	17	4	12	3	8	7	5	5	3	9	2	8	1	9	1	4	1	2	1	1	1	0

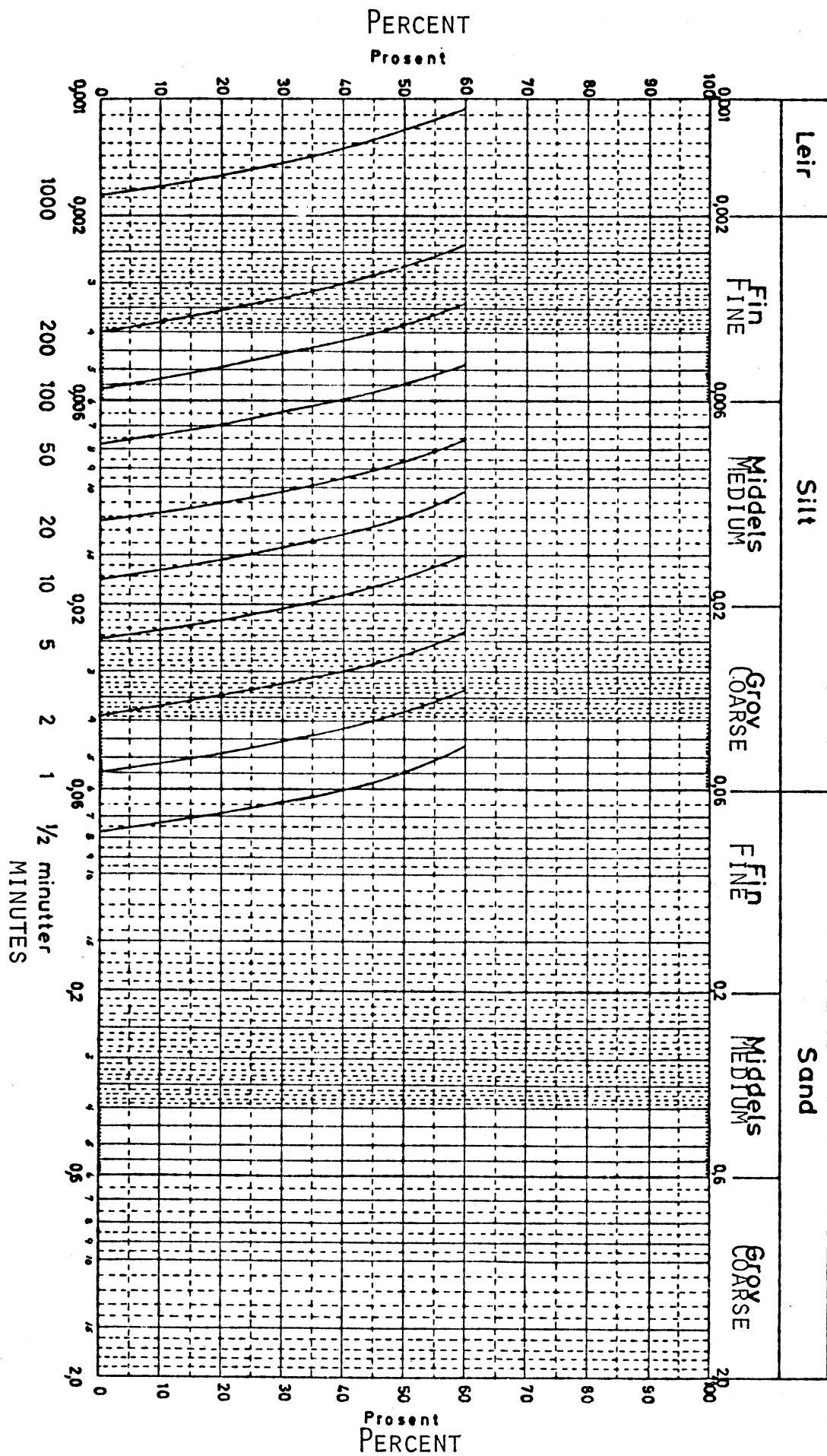
Hydrometer Reading (g/l)

Gandahl's Homegram for grain sizes in relation to settling time in minutes and hydrometer reading in g/l at 20°C and specific weight of soil 2.65 g/cm³.



CURVES FOR GRAIN SIZE DISTRIBUTION
KORNFORDELINGSKURVER

CLAY



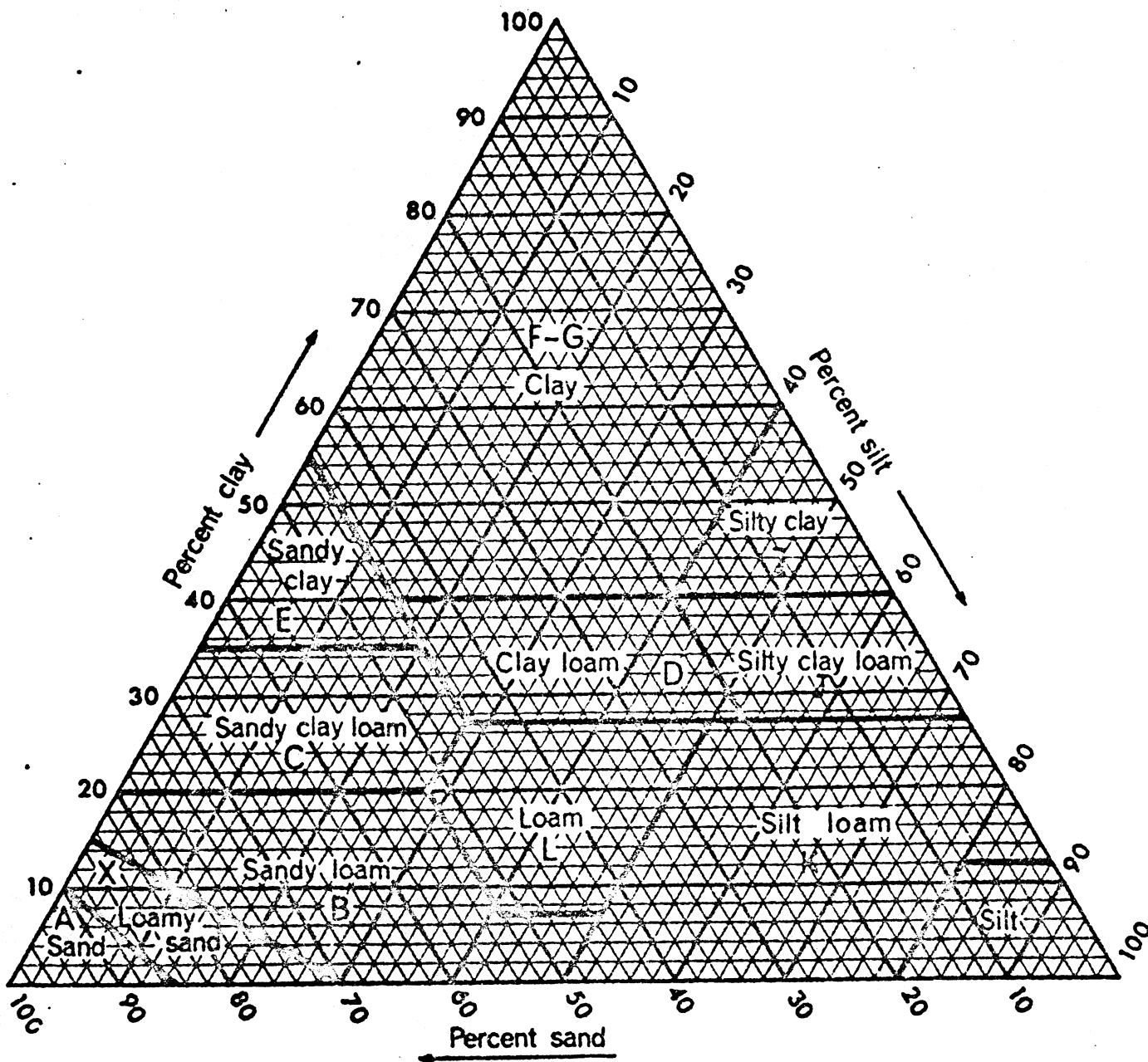


Chart showing the percentages of clay (below 0.002 mm.), silt (0.002-0.05 mm.), and sand (0.05-2.0 mm.) in the basic soil textural classes.

A-sand.

X-loamy sand.

B-sandy loam.

C-sandy clay loam.

D-clay loam.

E-sandy clay.

F-clay.

G-cracking clay.

I-silty clay.

J-silty clay loam.

K-silt loam.

L-loam.

11. Consistency of soil

A. Apparatus

Pestle and mortar. Cassagrande apparatus with accessories such as grooving knife, glass or respatex plate of approximately 10 x 10 cm, drying oven, drying ventilater, silicon grease, weighing beaker, spatula, moulds for shrinking limit, ballance with a precision to 0.01 g.

B. Sample preparation

Collect a representative sample of the soil, weighing approximately 200 g, for the determination of upper and lower plastic limits, stickiness limit, and shrinkage limit. The samples should be dried at a temperature not higher than 40-45°C before the treatment. Pulverize the sample in a mortar with a rubber-covered pestle and sieve the material through a 2 mm sieve. Remove the coarse particles and stones etc. Mix the soil thoroughly with distilled water to obtain a hard paste. Allow the soil to stand over night to obtain a uniform water content.

C. Floating limit - Upper plastic limit

1. Rinse the cup of the Cassagrande apparatus. Control that the maximum free distance between the cup and the contact point in the base is 1 cm.
2. Mix about 100 g of the hard paste thoroughly with distilled water until the sample gets a consistency of soft porridge. Place 30 cm³ of this porridge in the cup. Smoothen the surface level with the front of the cup to form a pot that is 1 cm thick above the point of contact. Make a groove with the help of a grooving knife in the direction from the bearing axle to the front. The walls of the groove should tilt 60° outwards and the width of the groove at the bottom should be 2 mm.
3. Turn the crank with a constant frequency of two revolutions per second. Record the number of rotations necessary to get the soil to float together and cover the bottom of the groove for a length of approximately 1 cm.
4. Remix the soil in the cup. Make a new groove and repeat step 3. If the number of rotations is within 1 or 2 of the

value obtained in step 3, and are between 12 and 38, consider the determination valid. If, however, the rotations are more than 38, add more distilled water, and if they are less than 12, add some more hard paste and mix thoroughly.

5. Take out 10 g portion of the soil which flowed together in the bottom of the cup and weigh it to 0.01 g. Use weighing beakers or plastic boxes. Dry it at 105°C to a constant weight.

Calculations: Loss of water = $\frac{\text{Loss in weight} \times 100}{\text{Net dry weight}}$

6. Repeat step 2, 3, 4, and 5 two or more times after adding more of either the hard paste or distilled water, so that at least 3 measurements fall between 12 and 38 rotations, with some above and some below 25 rotations.

7. Draw a diagram with water content along one axis and the rotations along the other. Draw the straight line which gives the lowest deviation and find the water content at 25 rotations. The value is reported as a whole number in percent, and is called the floating or upper plastic limit.

D. Rolling limit - lower plasticity limit

1. Knead 10-15 g of the hard paste to a ball.

2. Roll out the soil on a glass plate or respatex plate with the fingers until a thread of 3mm in diameter is formed. Remold the thread into a ball again.

3. Repeat step 2 until a thread is obtained which begins to crumble when it reaches a diameter of 3 mm.

4. Weigh the crumbling soil immediately to 0.01 g and dry it in an oven at 105°C to a constant weight. Calculate the water percentage as for the upper plastic limit.

5. Repeat step 1-4 to obtain 3 determinations.

6. The lower plastic limit is the average value of the three determination and is reported in whole numbers of percent.

E. Plastic index = Floating limit - Rolling limit

= Upper plastic limit - Lower plastic limit

F. Sticky limit

1. Place about 50 g of the hard soil paste on a glass plate.
2. Add a small amount of distilled water and make a homogenous paste with a stainless steel spatula.
3. Draw the clean spatula blade across the surface of the soil, exerting a firm pressure against the soil, to test for adherence.
4. If the soil does not adhere to the spatula, repeat step 2 and 3 until the water content is sufficient and adherence is starting. This is the sticky limit or sticky point.
5. Take 10 g of the soil sticking to the spatula and weigh it immediately to 0.01 g. The water content is determined as earlier.
6. Repeat the procedure in steps 1 to 3, consider the test valid, if the water contents agree within 2%.
7. The sticky limit is the average of the two determinations and the value is reported in whole numbers of percent.

G. Shrinking limit and linear shrinkage

1. The shrinking moulds are cleaned and covered by a thin silicon film.
2. A part of the remaining paste is mixed with distilled water, so that the water content is close to the upper plastic limit.
3. Place the paste in the form. Shake carefully the form to get the air out and smoothen the soil around the corners. Remove the soil outside the mould with a moist rag.
4. Place the soil paste for drying at 60-65°C in an oven without pressure and keep it there until it has shrunk away from the walls.
5. When the soil becomes of lighter colour, take it out for the determination of the water content by the method described in previous sections.
6. Let the other mould stand until no measureable shrinkage is observed. Measure the length of the soil in the mould.
7. Number of replications = 2-3.

8. Calculations:

a. Shrinking limit: $\frac{\text{Loss in weight} \times 100}{\text{Net dry weight}}$ (whole numbers of percent)

b. Linear shrinkage: $(1 - \frac{\text{length of dry soil}}{\text{starting length}}) \times 100$ (whole numbers of percent)

12. Specific surface of soils. Ethylene glycol method.

The term "specific surface" refers to area per unit weight of soil or clay and is usually expressed in m^2/g .

Several absolute methods of measuring the specific surface have been derived from fundamental principles of thermodynamics, electrostatics, and kinetics. These methods have a firm theoretical basis. Most relative methods are based on adsorption of polar molecules, such as ethylene glycol or glycerol. These methods are normally easy to use. By comparing the results obtained from the absolute and relative methods, along with theoretical calculations, the relative methods were found to be rather reliable.

Clay minerals show a great variation in specific surface which vary from $30 \text{ m}^2/\text{g}$ for kaolinite to about $800 \text{ m}^2/\text{g}$ for montmorillonite and vermiculite. Clay minerals adsorb polar molecules from the liquid as well as from the gaseous phase. Clay-water complexes are examples of such adsorption phenomena in the natural state.

Ethylene glycol and glycerol have shown to be held in two layers in the expanding portion of montmorillonite, resulting in a C-spacing of 17.1 \AA and 17.7 \AA , respectively. Vermiculite, on the other hand, adsorb only one layer of these polar molecules, giving about a 14 \AA C-spacing.

A monolayer of ethylene glycol corresponds to $0.00031 \text{ g per m}^2$ (Dyal and Hendricks, 1950). A complex of CaCl_2 -ethylene glycol has been used to maintain the vapor pressure slightly less than that for a monolayer on the clay mineral surfaces (Bower and Goertzen, 1959). If a small soil sample is saturated with ethylene glycol in a desiccator, where CaCl_2 -ethylene glycol complexes also exist, it is possible to obtain equilibrium after some time.

It should be mentioned here that vermiculite and hydrated halloysite absorb only one layer of ethylene glycol between the layers. An estimate of the amount of vermiculite may be obtained by determining the amount of glycol retained before and after saturating samples with potassium. Potassium collapses the vermiculite and thus the change in amount of glycol retained may be associated with internal vermiculite surfaces. To express the specific surface in terms of both sides of the interlayer spaces of vermiculite, the change in weight of glycol retained per gram sample may be added to the weight of glycol retained per gram by the sample before the material was saturated with potassium. The sum is then divided by 0.00031 to obtain the total specific surface in m^2/g .

If it is presumed that no reactions take place between the alcohol in the ethylene glycol and the groups of organic matter, the method can also be used for determination of specific surface of humus.

One condition for using this method for mineral material is that the vapour pressure of ethylene gas on the inner and outer surfaces must be the same.

Apparatus:

1. Pyrex vacuum desiccator, 25 cm in diameter and with porcelain plate.
2. Vacuum pump capable of reducing the pressure to 0.025 mm of Hg.
3. Aluminium boxes having a diameter of 6 to 7 cm and a height not exceeding 2 cm. It must be possible to close them at the time of weighing.
4. Balance with a precision up to 0.1 mg.

Reagents:

1. Ethylene glycol (Eastman). Take reasonable care to prevent contamination of the glycol by water vapour. If large amounts of contamination are suspected, redistill the glycol under reduced pressures discarding the first and last 10% of the distillate.

2. P_2O_5 , granulated.
3. $CaCl_2$ -40 mesh - anhydrous reagent grade.

Preparation of ethylene glycol - calcium chloride solvate

Weigh approximately 120 g of 40 mesh $CaCl_2$ into a 1-liter Pyrex beaker and dry it at 210° to remove all traces of water. After the $CaCl_2$ has been more than one hour in the oven, weigh 20 g ethylene glycol into a 400 ml Pyrex beaker. Remove the $CaCl_2$ from the oven, weigh out 100 g of the salt without cooling, and put it into the beaker containing the glycol. Mix the contents immediately and thoroughly with a spatula. After the solvate has cooled, transfer it to a wide porcelain crucible. Store the chamber and contents in a sealed desiccator.

Determination of the specific surface

Weigh 0.3 g of clay or 1.1 g of soil into a tared aluminium box. Spread the sample evenly over the bottom of the box. Place the box with lid removed in a vacuum desiccator over about 150 g of P_2O_5 . Evacuate the desiccator by applying a vacuum pump for one hour. Close the stop-cock and dry the sample to constant weight. Constant weight usually is attained within 5-6 hours, when no more than four samples are in the desiccator. Weigh the sample to 0.1 mg, using care to minimize adsorption of atmospheric water. Wet the sample with about 1 ml of ethylene glycol (if it is a soil sample) by distributing the liquid dropwise from a pipette over the surface of the sample. Wetting may be facilitated by warming the box for a few minutes in an oven at 50 to $60^\circ C$. Place the samples around the porcelain crucible containing ethylene glycol- $CaCl_2$ solvate in a desiccator. Evacuate the desiccator by applying a vacuum pump for one hour. Close the stop-cock and allow the desiccator to stand at a constant temperature ($25^\circ C$). After 24 hours apply the vacuum pump again for 30 minutes to remove any foreign vapors which may have reduced the vacuum. When the box has been in the desiccator for about 48 hours, release the vacuum, open the desiccator, place the lid on the aluminium box to prevent adsorption of H_2O by the sample. Weigh the box and sample, then place the lid under the box. Evacuate the desiccator by applying a vacuum pump for 30 minutes and close the stop-cock. After the desiccator has been

allowed to stand at $25^{\circ} \pm 1^{\circ} \text{C}$ for an additional 8 to 16 hours, weigh the box again. Repeat these operations until two successive weighings agree within a few tenths of a milligram. If surface area determination are made on several samples concurrently, a point is often reached when some samples appear to gain and some to lose a fraction of a milligram of weight between two successive weighings. This is a good indication that equilibrium has been attained. Use the mean of two successive weights that agree within a few tenths of a milligram to calculate the amount of glycol retained by the sample. Calculate the specific surface by the equation

$$A = \frac{WG}{WS \times 0.00031}$$

A = Specific surface in m^2/g

WG = Weight of ethylene glycol retained by the sample in grams

WS = Weight of P_2O_5 - dried sample, in grams

0.00031 is the Dyal-Hendricks value for the gram of glycol required to form a monolayer on a square meter of surface.

Comments

The vacuum pump and the desiccator should be connected by means of tight-fitting, vacuum-type-rubber tubing, a glass tube filled with 8-mesh CaCl_2 . High vacuum stop-cock grease should be used to prevent leakage. A container with some water may be placed between the glass tube and the pump, so that it is easy to see the water bubble.

The air flow to the desiccator should be through CaCl_2 when releasing vacuum. The lids on the weighing boxes should be placed promptly and weighing should be done rapidly. The precautions will prevent the adsorption of H_2O by the sample during weighing. The P_2O_5 employed for drying may be used until it develops a syrupy consistency.

References

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13. Density of soil particles or material density

Particle density is expressed as the ratio of the total mass of the solid particles to their total volume. Units used are g/cm^3 or kg/litre or tonn/m^3 .

Principles

Particle density of a soil sample is calculated from two measured quantities, namely, mass of the sample and its volume. The mass is determined by weighing the sample after drying it at 105°C to a constant weight. The volume can be determined by different methods as mentioned below.

1. Liquid pycnometer
2. Filling up of a measuring flask with alcohol
3. Air pycnometer

Method 1

a. Apparatus: Pycnometer with a capillary opening in the stopper, thermometer and balance (0.001 g)

b. Procedure: Weigh a dry, clean pycnometer in air. Fill in 10 g of dry soil. Clean the outside and neck of the pycnometer carefully. Weigh the pycnometer and soil, including stopper. Fill the pycnometer about one-half full with distilled water. Remove entrapped air by gentle boiling of water for several minutes with frequent gentle agitation of the contents or by putting the pycnometer in a vacuum desiccator. Record the temperature. Cool the pycnometer and its contents to room temperature and then add enough boiled or airfree distilled water to fill the pycnometer. Insert the stopper and seal it carefully. Weigh the pycnometer and its content and record the temperature of the contents. Remove the soil from the pycnometer and clean it. Fill the pycnometer with boiled, cooled distilled water at the same temperature as before, insert the stopper and weigh the pycnometer and contents and measure the temperature.

c. Calculations:

$$\text{Particle density} = \frac{DV(P2-P1)}{(P2-P1)-(P3-P4)}$$

where

DV = density of water at the temperature observed, in g/cm^3

P1 = weight of pycnometer

P2 = " " " + soil

P3 = " " " + " + water

P4 = " " " + water

Method 2

a. Apparatus:

100 cm^3 flask, automatic-burette, container for alcohol, balance (0.01 g), and thermometer.

b. Procedure: Dry the soil at 105°C for overnight. Weigh about 50 g of the dried soil into a 100 cm^3 measuring flask. Fill the flask up to the mark with alcohol. Remove entrapped air by gentle knocking with a plastic- or rubber hammer. Record the volume to the nearest 0.05 cm^3 .

c. Calculations:

$$\text{Particle density} = \frac{\text{Dry weight of soil}}{100.00 \text{ cm}^3 - \text{added volume of alcohol}}$$

Another method to calculate particle density is to weigh the measuring flask + soil and the measuring flask + soil + alcohol. The equation thus used is as follows.

$$\text{Particle density: } \frac{DA(P_2 - P_1)}{100 \times DA - (P_3 - P_2)}$$

DA = Density of alcohol at the temperature observed.

P_1 = Weight of the flask

P_2 = " " " " + soil

P_3 = " " " " + " + alcohol

The last quantity may be difficult to read exactly to 100 cm^3 and gives an inaccurate volume. Thus the last mentioned method is considered as a rough method.

13.1 Bulk density of clods

Principle

The bulk density of clods can be calculated from their mass and volume. The mass is determined as net dry weight of the clod. The volume is determined by coating the clod with paraffin or any other water-repellant substance and by weighing it first in air and then again while emersed in a liquid of known density, making use of Archimedes principle.

Apparatus

A. Special balance for example Jolly or Westphal, modified to accept a container basket for the sample. The basket can be attached to the balance lever arm by a thin wire. A coarse-mesh wire pan or basket to contain the sample while it is being dipped in paraffin and while it is being weighed. Thin wire mesh of 1 to 2 mesh per inch, will keep the amount of paraffin held by basket to a low value.

Paraffin in a container kept at, or a few degree above, 60°C.

Procedure

Dry the clod at 105°C to a constant weight, or use air dried clod, but in the last mentioned case water content need to be determined after the analysis is finished. The first method is commonly used.

Weigh the wire basket and the clod + wire basket. Dip the wire basket with the clod momentarily in melted paraffin, and allow the excess to drain. Let it cool down until the thin layer of paraffin gets solidified. Repeat the dipping procedure until the whole surface is covered. Weigh the clod covered with paraffin + wire basket. Suspend the system in water and weigh it again. Determine the weight of basket in air and in water.

Calculation:

Calculate bulk density (D) of clod as follows:

$$D = \frac{DV(P_2 - P_1)}{(P_2 - P_1) - (P_6 - P_5) + (P_3 - P_4 - P_2 + P_1) - (P_3 - P_4 - P_2 + P_1)} \times \frac{DV}{DP}$$

DV = Density of water at temperature of determination.

P₁ = Weight of wire basket in air

P₂ = " " " " + soil in air

P₃ = " " " " with paraffin + soil with paraffin
in air

P₄ = " " " " with paraffin in air

P₅ = " " " " " " " water

P₆ = " " " " " " + soil with paraffin
in water

DP = Density of paraffin, about 0.9 g/cm³

The formula may be simplified to the following form:

$$D = \frac{DV(P_2 - P_1)}{(P_3 - P_4) - (P_6 - P_5) - (P_3 - P_4 - P_2 + P_1) \times \frac{DV}{DP}}$$

15. Water permeability in soils (measurement of hydraulic conductivity)

Introduction

The rate of movement of water through the soil is of considerable importance in many aspects of agricultural and urban life, such as the movements of water to plant roots, the flow of water to drains and wells, and the evaporation from the ground surface. In the subsequent discussion the term water conductivity in soil, i.e. the ability of the soil to transmit water, will be used in order to have the expression similar to electric conductivity and thermal conductivity etc.

Water movement in soils takes place through the pore system and the shape of the pore system (size distribution and continuity), therefore, determines the velocity of the water movement. If it was possible to determine the pore size distribution and the continuity of the pores with high enough precision, then it would be possible to calculate the water conductivity of soils. This is not the case, and therefore the characteristic soil water constant has to be determined experimentally.

The water conductivity (permeability) of a soil is maximum when the pore system is completely saturated with water. This characteristic constant is called the permeability or percolation constant.

The conductivity of soil to water decreases because the pore system contains air, and the formulation capillary conductivity is used.

Principle

Water moves through a soil in response to various forces acting upon it. Among these are the pressure-gradient, gravitational, adsorptive and osmotic forces. Besides, thermal and electrical gradients can influence the movement of water. Water movement occurs only when the pressure or the potential of the water is different between two points in the soil or in other words, the pressure or the energy gradient is present. If the gradient is 0, no movement will occur. One of the basic physical relationships used to describe the flow of water in

soils is a flux equation, which can be formulated as Darcy's law, as given below.

For a given liquid at a given temperature the average rate of the liquid's flow through a porous material (the ground) is proportional to the actual pressure gradient in the direction of the flow.

The equation can be written:

$$v = Ki \quad (1)$$

v = water volume passing per unit surface and per unit time (LT^{-1})

K = hydraulic conductivity (LT^{-1})

i = hydraulic-head gradient

The hydraulic-head gradient can be expressed:

$$i = \frac{H}{L} \quad (2)$$

H = Hydraulic head. Equal to the height of the water surface above the reference level, (L)

L = Length of the transport distance.

From (1) and (2) the law of Darcy can be written:

$$\frac{Q}{At} = K \frac{H}{L} \quad (3)$$

Q = volume of flow (L^3)

A = cross-sectional area of flow (L^2)

t = time (T)

In figure 1

$H = h + z$ = hydraulic head (L) (4)

h = pressure height (L)

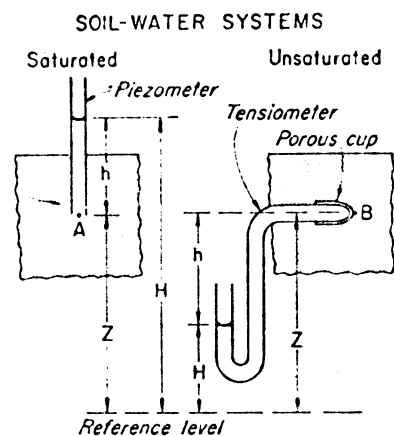
z = gravitational height (L)

In figure 1 the soil is saturated with water at A and unsaturated at B. In saturated conditions the hydraulic head is measured with a piezometre and in unsaturated conditions with a tensiometre. At A the pressure gradient is positive and at B (unsaturated) it is negative. This is easily understood if the reference level is kept together with the measuring level. In both cases, the sum of the pressure head and gravitational head is equal to the hydraulic head.

The conductivity (permeability) of water in soils is not only a function of the porous material, but also of the viscosity and the density of water. The conductivity (permeability) of water will decrease with decreasing temperature, whereas the viscosity of the water will increase with decreasing temperature (about 3% per centigrade decrease). The influence of temperature on the density of the water is much less than on the viscosity. The flow velocity at the moon, if the other conditions are not changed, will be only 1/6 of that on the earth because of difference in acceleration by gravity.

The percolation constant is not absolute constant, because for example, change in the structure of the porous medium changes the water conductivity (permeability) in soil. Differences in the ionic-composition or concentration in the flowing liquid may also cause change in the conductivity (permeability). Leaching of soil with distilled water also causes in many cases, a decrease in the conductivity of water because of swelling of the colloides or dispersion. If possible, water to be used for conductivity determination should have the same chemical properties as the ground water. Because the chemical properties of the soil water are not known, ordinary water is normally used for conductivity determination.

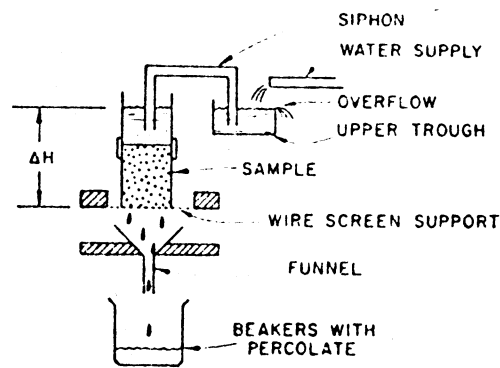
Fig. -1. A diagram of the relationships between hydraulic head H , pressure head h , and gravitational head Z . The pressure head is measured from the level of termination of the piezometer or tensiometer in the soil to the water level in the manometer and is negative in unsaturated soil.



15.1 Hydraulic conductivity by constant head method

Apparatus

Flask 4 l, Kork (NS 36) with two 0.7 cm wide holes, T tube (0.7 cm outside diameter) rubber tube, beaker (200 ml), measuring cylinder (200 ml), rubber klamp, one straight glass tube of about 25 cm length and outside diameter of 0.7 cm, one bended glass tube of about 20 cm length and 0.7 cm outside diameter, cylinder stand, flow apparatus with inlet for water at the bottom and outlet in the stopper. A simple apparatus is shown in fig. 2.



ΔH = Hydraulic head difference across sample

Fig. 2 Diagram of the constant-head system for conductivity measurement.

Procedure

Cover one end of each sample with a piece of cloth held in place with a rubber band. Place the samples, cloth covered ends down in a tray filled with water to a depth just below the top of the sample. Allow them to soak at least 16 hours or longer if they are not completely saturated.

Turn on the water supply to the upper trough. Connect an empty cylindrical sample holder to the top of each sample, using a large rubber band or waterproof tape. Leave the lower part of the sample in the water, while this is being done. Place a small piece of blotting paper on the top of the sample. Slowly pour water into the upper cylinder until it is 2/3 to 3/4 full. Quickly transfer the sample to the rack, and start one of the siphons to maintain a constant head of water on the sample. Do not allow the water to drain from the top of the sample.

After the water level on the top of the sample has become stabilized, collect the percolate in a beaker. Measure the volume of water Q that passes through the sample in a known time T . Measure the hydraulic head difference ΔH and the temperature of the water.

Calculations

Calculate the hydraulic conductivity by the use of the following equation

$$K = (Q/AT) (L/\Delta H)$$

where

- K = hydraulic conductivity, cm/sec
- Q = volume of the water, cm^3
- A = cross sectional area of the sample, cm^2
- T = time · sec
- L = length of the sample, cm
- ΔH = hydraulic head difference, cm

15.2 Hydraulic conductivity by falling gradient method

Apparatus

100 cm³ steel cylinders

Perspex cylinders graded on the side

Piece of bicycle inner tube

Perforated bottom for the steel cylinders

Plastic vessel for saturation

Meter scale

Stop watch

The perspex cylinders have the same inner diameter as the steel cylinders.

Procedure

Place the steel cylinders with soil in natural conditions in a plastic vessel for saturation and allow them to soak for 16 to 24 hours. In the beginning of the saturation about 1 cm water is filled in the saturation vessel. Distilled water should be used to avoid replication variations. When the surface of the soil samples is wet, raise the water level in the saturation vessel to the level of the soil surface.

After the saturation, take out the soil cylinders and put on the perforated bottoms. Place the cylinders with the sharp end down. Buckle up the perspex-cylinder with the help of a piece of bicycle inner tube to the sample cylinder, filled up nearly full with distilled water. With a series of determination, all cylinders should be arranged properly before filling up them with water. Record the time needed for hydraulic head to fall from a known level to a lower level. Alternatively, the hydraulic head fall in 15 minutes can be recorded. This may save time in conducting the experiment in heavy textured soils. The hydraulic head full of about 0.5 to 1.5 cm is sufficient in heavy textured soils.

Finally, the soil cylinders are closed with plastic lids and stored for other determinations.

Calculations

Calculate the hydraulic conductivity by the use of the following equation.

$$K = (a/A) (L/T) \ln (H_1/H_2)$$

or

$$K = 2.3(a/A) (L/T) \log H_1/H_2$$

where

K = hydraulic conductivity, cm/sec

a = cross section area of perspex-cylinder cm^2

A = " " " " soil cylinder cm^2

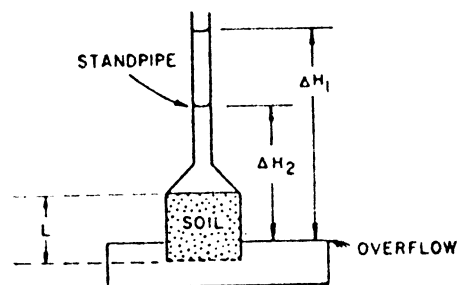
L = length of soil samples

t = time sec

H_1 = height from the bottom of the cylinder to the water surface at the start, cm

H_2 = height from the bottom of the cylinder to the water surface at the end, cm

Fig. 3 .. Diagram of the falling-head system for conductivity measurement.



16. Aggregate size distribution

Dry aggregates

Apparatus:

The motor driven sieving apparatus consists of 1/2 h.p. electro motor, two intermediate shafts (one with eccentric disk), transmission, and a frame with leading axels where the sieving set are carried back and forth on a sliding bearing.

The sieving set consists of the following coarse sieves: 20 mm, 6 mm, 2 mm, and 0.6 mm. Under 0.6 mm sieve is placed shovel to collect the soil-particles with a diameter less than 0.6 mm. Thus, total 5 fractions will be collected. Each sieve is 446 mm long and 247 mm broad. The height of the wodden frame arround each sieve is 60 mm. Each sieve frame is placed over each other by means of nuts and springs. The sieving apparatus is closed on top during use. The eccentric disk makes 240 strokes per minute. The sieving apparatus gets a corresponding stroke. The sieving apparatus moves horisontally in the direction of the length of the apparatus.

Preliminary treatment

The boxes are opened immediately after they are transported to the store room and dried at the normal room temperature.

Analysis

The samples are weighed up to 1 g accuracy. A balance with tare or a big pan suits best. The sample is emptied on to the upper most sieve and levelled carefully and the motor is switched on.

The sieving continues for 3 minutes and after sieving, different fractions are weighed.

Calculations

Each fraction is calculated as per cent of the total sample. Normally a small part is lost as dust.

Special measures

The room where the sieving is carried out should be well ventilated because of the dust.

16.1 Aggregate stability

By Simulated rainfall method

Apparatus:

Connection to watertube, reduction valve, manometer plastic tube, T-tube, electric motor with sprinkler arm for mounting of two pairs of nozzles, 0.5 mm mesh sieves, metal frame, porcelain cups, toilet paper, balance (0.1 g), drying oven, plastic basin.

For normal aggregate stability determinations, Tee-jet tubes nozzles with 0.5 mm openings and the length direction of the opening crosswise to the direction of the movements of the sprinkler arm are used.

Procedure:

Weigh 2 x 20 g samples of dry soil from 6-2 mm or 2-0.6 mm aggregate size (if bigger aggregates are used, 2x40g samples should be used). Place the samples on different sieves and spread them uniformly over the surface. Place the sieves on the plastic basin in such a way that the distance from the nozzle to the sieves is about 32 cm and that the two sieves touch each other in the middle under nozzle, when the sprinkler arm is in midposition. Place two other sieves in the same way under the second nozzle.

Start the sprinkler but take care that the sprinkler arm is in end position so that no rain falls directly on the samples during the pressure adjustment. Pressure used for the water is 1 bar. Let motor work for 3 minutes. The sieves are rotated 1/4 round each half minute. After 3 minutes, shut off the water and stop the motor.

Porcelain cups are used to collect the soil from the sieves. Put piece of toilet paper in the bottom of each cup. Wash off the remaining aggregates with water on the toilet paper, and decant the water. Fold the toilet paper in such a way that the remaining part of the sample is wrapped up in the paper. Place the binder around the paper to prevent loss of the soil.

Dry the samples at 105°C in a drying oven for a minimum of 4 hours and weigh them.

Calculations:

$$\text{Aggregate stability} = \frac{\text{Weight of dry soil after rain}}{\text{Weight of dry soil before rain}} \times 100\%$$

16.2 Aggregate stability

By Henin et al. method

Principles:

The aggregates are treated with different liquids to determine the stability against break down.

Apparatus:

250 ml beakers

500 ml Erlenmeyer flasks

0.2 mm sieve, about 10 cm in diameter, if possible

Porcelain crucibles

Bucket or tank of ab. 25 cm diameter

Reagents

96% ethanol

Benzine

Distilled water

Procedure

Take 3 x 10 g samples of dry soil from 0.6 - 2 mm and 2-6 mm aggregates or from one of the fractions after dry sieving.

Put the samples in 250 ml beakers. Add 10 ml ethanol to the first beaker, 10 ml benzine to the second, and fill the third beaker with distilled water after five minutes.

Pour the whole contents of each beaker to the 500 ml erlenmeyer-flasks (Note! The aggregates must be transferred very carefully).

Fill the erlenmeyer-flasks with distilled water to 300 ml mark, and shake end over end 20 times.

Pour the contents of the flasks on 0.2 mm sieves. Fill bucket with distilled water. Sink sieve in water til the water stands 2-3 cm above the bottom and lift up. Repeat the procedure 20 times. Transfer the aggregates over to a paper in a porcelain crucible (or a beaker) and dry over night at 105°C and weigh to 0.1 g.

Carry out the mechanical analysis on the same material.

Calculations:

$$A = \text{aggregate stability: } \frac{\text{Dry weight (0.1g precision)}}{10.0 \text{ g}} \times 100$$

$$S = \frac{m}{\frac{A_1 + A_2 + A_3}{3} - 0.9 \times p}$$

S = aggregate stability index

m = mass of particles smaller than 20 μm in 10 g

p = percents sand, 0.2-2.0 mm

A₁ = aggregate stability in distilled water

A₂ = " " in alcohol (ethanol)

A₃ = " " in benzine

Log₁₀S should be calculated

Remark 1: To prevent flocculation by the mechanical analysis, 10 ml 1-N Na-citrate can be added to 1000 ml cylinder and the cylinder should be turned upside down or stirred.

Remark 2: It is not necessary to calculate S for normal use. Instead the mean aggregate stability, \bar{A} , can be calculated. It should always be remembered that very seldom soils will be exposed to rain of alcohol and benzine.

References:

HENIN, S., MONNIR, G., COMBEAM, A. 1958. Method pour l'étude de la stabilité structurée des sols. *Annuaire Agronomiques*. I, 1958, 11-90.

17. Heat of immersion

Principle:

When completely dry soil is moistened, energy (heat) is evolved. Temperature difference in the system depends upon the specific heat capacity of water and of soil, heat leakage, and friction heat from stirring. The friction heat and the heat leakage are summed up to a apparatus constant, k , which can be determined by supplying a known amount of energy for example, electrical energy, under the conditions of the measurement.

Equipment:

Calorimeter (Dewar bottle, or thermo bottle)

Beckman thermometer, placed through a cork fitted to the calorimeter

Sample tube, 10 ml with cork

Isolated holder for the calorimeter (Isopor).

Procedure:

Transfer 2-10 g of soil, biggest quantity for coarse soil, is transferred to a sample tube and dry it over night at 105°C . Close the sample tube when it is still warm and weigh it when it has cooled down to room temperature. The sample tube should be placed in a constant temperature room so that the soil, after it has cooled down, has the same temperature as the calorimeter. Place about 0.5 l airfree water in the constant-room the evening before the determination.

Transfer 30 ml distilled water to the calorimeter. Place the thermometer in the cork in such a way that the end portion is 2 cm above the bottom of the flask. Record temperature when it has become constant. Remove the thermometer and pour the soil quickly into the water. Stir the contents carefully with the thermometer and close the flask. Mix the contents by rotating the complete apparatus carefully. Follow the temperature change until it has become constant and record the temperature after each half minute. The temperature difference $\Delta T = T_{\text{max}} - T_{\text{start}}$ is used in the calculations. Weigh the samples tube + cork after it is emptied and cleaned.

Calculations:

$$q = \frac{(CW \times 30 + CS \times M + k) \times \Delta T}{m}$$

CW = 1 cal/g/degree (Specific heat capacity for water)

CS = 0.2 cal/g/degree (" " " " soil)

m = net weight of dry soil

k = apparatus constant cal/degree

ΔT = max temperature ($^{\circ}\text{C}$) - initial temperature

Weight of soil sample + tube + cork after drying - weight of tube + cork = m

q = heat of immersion, cal/g

References:

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18. Material volume and material density

Principles:

The method is build on the following equation

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

P = Pressure of gas

V = Volume of gas

T = Temperature

1 = Condition 1

2 = Condition 2

If $T_1 = T_2$, we get Boyle - Mariotte law.

$$P_1 V_1 = P_2 V_2$$

It says that the product of pressure and volume is constant provided the temperature is constant.

The apparatus is build on two air volumes. One of the air volumes is regulated by means of a reference piston in a cylinder. At starting, the references wheel is put in end position and the air valve is closed. The piston goes to the inner position by turning the reference wheel clockwise til the piston goes against the stop point. This is volume 1, which corresponds to pressure 1. The other volume, the measured volume, corresponds to the volume of the measuring cylinder + the volume of the airfilled part of the beaker. At the start of the measurement, the measuring wheel is put to zero position, which on this scale corresponds to 106.3 cm³, and the coupling valve must open. The sample is placed in the beaker. The coupling valve is then closed. This means that the measured volume and the reference volume are not any more connected with each other, but they are connected with the pointer for the pressure difference between the two volumes. When the reference volume is fixed, the pressure in the measured volume must be regulated until there is no pressure difference. This gives $P_1 = P_2$, the two preasures are equal. Then it is possible to calculate V_2 from the following equation

$$V_2 = \frac{P_1 V_1}{P_2} = \frac{P_1 V_1}{P_1} = V_1$$

Position of the measuring piston will thus depend upon the size of the material volume of the sample in the measuring beaker. The apparatus is calibrated in such a way that indicator shows the size of the material volume when the indicator for pressure differences indicates 0.

Apparatus:

Beckman air comparison pycnometer

Beakers, 50 cm³

Calibrating balls, 8.58 cm³ and 28.96 cm³

Purge valve

Coupling valve

Counter scale and indicator for pressure differences

Suction feet

Beaker-holder with twist handle

Reference wheel

Measuring wheel

Zero adjustment screw

Plate for zero adjustment value

Procedure:

Place the apparatus on the bench in such a way that the wheels are to the right, the beaker-holder is to the left, and the counter scale and the zero indicator are on the side which points out into the room. The purge valve is behind and the coupling valve is in front. The reference wheel is behind and the measuring wheel is in front.

A. Zero test

1. Close the purge valve and open the coupling valve.
2. Turn both the wheels clockwise till they strike against the stopping end.
3. Turn the measuring wheel clockwise till starting number appears on the counter. The starting number is stamped on the measuring wheel.

4. Place one of the calibrating balls into the measuring beaker. Place the beaker into the beakerholder and close it by turning the twist handle down (use only a little force).
5. Close the coupling valve after 15 sec.
6. Turn both the wheels alternately or simultaneously inwards (clockwise). Take care that the pointer stands on zero whole of the time. Stop the turning when the reference wheel stops.
7. After 10 sec., turn the measuring wheel in such a way that the pointer for pressure difference points on 0.
8. Open the coupling valve. Read the material volume (cm^3) on the counter. This volume should correspond to the volume of the ball. If the reading does not correspond, repeat the complete procedure.

Note! The pointer not remaining on 0 after opening of the coupling valve, will signify that the pressure difference was not 0.

9. Take out the measuring beaker.

Remark. If the reading gives a higher value than the volume of the ball, the difference noted can be used as tare and subtracted from later readings.

If the reading gives a smaller value than the volume of the ball, the difference noted should be added to the later readings.

B. Measurement

1. Close the purge valve and open the coupling valve.
2. Turn the wheels clockwise till they stop.
3. Turn the measuring wheel clockwise till the start number appears on the counter.
4. Fill the sample into the measuring beaker. Place the measuring beaker in the beakerholder and close it by turning the twist handle down (use only little force).
5. Close the coupling valve after 15 sec.
6. Turn both the wheels simultaneously or alternately till the reference wheel stops. Keep the pointer on the scale whole of the time.

7. After 10 sec., turn the measuring wheel in such a way that the pointer for pressure difference points on 0.
8. Open the coupling valve. Read the material volume (cm^3) on the counter.
9. Turn both the wheels anticlockwise till they stop.
10. Take out the measuring beaker.
11. The pycnometer is now ready for the next determination which starts at point 3.

Remark 1. To obtain maximum precision, time of equilibrium required is 3-5 times longer than the usual.

Remark 2. Error with zero adjustment. If the pointer after opening the coupling valve always stays on a fixed value beside 0 (the pressure inside the system), then the error may be corrected in the following way:

1. Loosen the mounting screw on the 0-scale
2. Move the 0-scale until the hand stands on 0. Fix the screw.

Measurement of material density

1. Weigh a sample of 10-40 cm^3 volume
2. Dry it over night at 105°C
3. Measure the material volume
4. Calculate the material density

$$d = W/v$$

$$d = \text{density, g/cm}^3$$

$$W = \text{weight of dry sample, g}$$

$$V = \text{volume of dry sample, cm}^3$$

Determination of air content in soil with air-pycnometer

Principles

The general formula for gasses $PV = nRT$ is the basis of measurement and if the temperature and matter contents are supposed to be constant, one gets the law of Boyle Mariotte $P_1V_1 = P_2V_2$. In practice all the volumes inside the system of measurements are kept constant and quite close to the air volume. By using the constant soil volume, for example 100 cm^3 , one can calibrate the instrument to show percent volume of air. In soils, air volume = soil volume - material volume - water volume. By calibration the material volume is exchanged with water volume, or the vice-versa in order to get a more simple measurement.

Apparatus

100 cm^3 steel cylinders with plastic lids
 Transportation box
 Driving head
 Rubber hammer
 Spade or trowel
 Knife with grooved edge
 Air-pycnometer
 Compressed air system with reduction valve and manometer
 Water container
 Calibrating cylinder with brassdisks
 Strips with grapp paper
 Pipettes (2 ml, 5 ml and 10 ml)

Calibration

1. Control that the cocks are tight
2. Place the graph paper strip on the scale rod and screw up the scale rod. Put the graph paper approximately at the same place as the scale. Draw a line with a black pencil on the upper and lower edge of the paper on the scale rod and mark them with 20 and 0 cm, respectively.

3. Place 20 cm³ brass disk in the calibration cylinder. The cylinder is an open 100 cm³ steel cylinder, slightly grinded on the inside walls. Put on the starting pressure and let the air into the cylinder. Record the reading. Repeat 3 times.
4. Repeat step No 3 with 10 and 5 cm³ brass disks several times until the material volume is 100 cm³ and the air volume is 0 cm³.
5. Calculate the average readings. Draw a curve and prepare the scale on a white drawing paper, which is as long as the strip of the graph paper. Fasten the scale on the rod with the upper edge at the upper pencil mark and the lower edge at the lower pencil mark.

Instead of open cylinder and disks, a cylinder with bottom and adjustable water-volume can also be used. In that event, correction for the volume of the cylinder bottom has to be made and brass disks placed in the cylinder.

Analysis

Control that the scale stands correct after placing brass disks in the cylinder.

Example: With little air 90 cm³ corresponds to 10 volume % air
 " " medium " 70 " " " 30 " " "
 " " high " 50 " " " 50 " " "

Sampling

The samples are taken with 100 cm³ sampling cylinders. The cylinders are pressed down into the soil with the sharpened edge downwards. In hard soils, the cylinder is pressed down with a driving head. The driving head must have the same inner diameter as the cylinder.

When the cylinder has gone deep enough, it is taken out by cutting the soil under the cylinder, but care should be taken that there is no empty space inside the cylinder. It is better to take some extra soil around the cylinder.

The extra soil is removed by cutting it away with a knife. Plastic lids are placed on both ends.

Take a representative sample of the treatment to be examined. Take minimum 3 replications.

The samples are stored in a transportation box. The lock of the box is constructed in such a way that the samples are kept on its place during transportation.

Scheme for calibration

Disks	Airvolume	Reading				Average
		1	2	3	4	
20 cm ³	80%					
+10 "	70%					
+10 "	60%					
+10 "	50%					
+5 "	45%					
+5 "	40%					
+5 "	35%					
+5 "	30%					
+5 "	25%					
+5 "	20%					
+5 "	15%					
+5 "	10%					
+5 "	5%					
+5 "	0%					

Specific electrical conductivity = electrolytical conductivity

Principle:

The specific electrical conductivity is a characteristic material constant for a liquid. The word specific means in this connection the conductivity in a liquid - volume with a cross section of 1 cm^2 and a length of 1 cm . Electrical resistance in a normal conductor is $R = r L/A$, where

R = electrical resistance (ohm)

r = specific electrical resistance (ohm cm)

L = length of the conductor (cm)

A = cross section of the conductor (cm^2)

Specific electrical conductivity

$$s = 1/r \text{ with denomination Siemens/cm (S/cm)}$$

$$1\text{S/cm} = 1 \text{ Siemens/cm} = 1/\text{ohm cm} = \text{mho/cm}$$

$$1\text{mS/cm} = 1 \text{ milli Siemens/cm} = 1 \text{ mmho/cm}$$

$$1\mu\text{S/cm} = 1 \text{ micro Siemens/cm} = 1 \mu \text{ mho/cm}$$

The measurements of electrolytical conductivity is done by resistance measurements in a Wheatston's bridge, by using high frequent alternating current to avoid polarization of the electrodes. The measurements are done with a cell with 2 or 4 platina electrodes with a given distance and cross section. The dimensions of the measurement cell corresponds to the cell constant, C , which can be determined by using solutions with known conductivity. If the resistance of the liquid is measured with the apparatus, the conductivity can be calculated out of

$$S = C/R$$

where

C = the cell constant

R = resistance

Many new apparatus have automatical compensation for the different cells, and the conductivity can be read directly. Solutions of different substances have different conductivity. The expression eqivalence - conductivity can be used for a certain ion with indefinite dilution.

The table shows how the equivalence - conductivity, S^i , is dependent upon the kind of ion and the temperature.

Kind of ion	0°C	25°C	50°C
H ⁺	240	350	465
OH ⁻	105	192	284
SO ₄ ⁻⁻⁻	41	79	125
Cl ₄ ⁻	41	76	116
K ⁺	41	75	115
Na ⁺	26	51	82
Ca ⁺⁺	30	60	98

It is better to standardize the measurements at about 25°C. With decreasing pH increases the conductivity under otherwise equal conditions. The contribution of the H⁺ ion to the conductivity can be calculated as shown in the following example, where the conditions of the solution is pH 3 at 25°C.

$$s(H) = 350 \times 10^{-3}/10^3 = 350 \times 10^{-6}$$

We multiply with 10^{-3} because pH 3 corresponds approximately to 10^{-3} mol/litre, and we divide with 10^3 to convert litres into cm^3 . The contribution of the H⁺ ion is in this case $0.350 \text{ mS/cm} = 0.350 \text{ m mho/cm}$.

Equipment

Buchner funnel, flask, vacuum distributor, watch glass, washing bottle for distilled water, filter paper, 25 ml measuring glass, conductivity meter with electrode, marking pencil.

Procedure

Sieve the soil through a 2 mm sieve, and put about 100 cm^3 of loose soil on a filter paper in a Buchner funnel. Add distilled water until the surface of the soil is shining. After a few minutes add more water. If some drops come into the flask, pour them back to the soil. If the soil is not already saturated, add more water just before the day is finished, and cover the funnel by a watch glass. The next day put on the vacuum and allow the suction to go until air comes through the sample. Measure the conductivity of the extract. Note: Read on the correct scale. If there is too little extract, the extract can be diluted to 1:2, but be sure that distilled water is used. The result can be given as μS or $\mu \text{ mho/cm}$ for normal soil, or mS/cm or m mho/cm if higher salt concentrations.

Remarks

It is possible to use approximation formulas to calculate the salt concentration and the osmotic pressure:

Salt concentration, mg/litre	= 640 x s, m S/cm
Cation concentration, me/litre	= 10 x s, mS/cm
Osmotic pressure	= 0.36 x s, mS/cm

Tolerance limits can be established for plants in soil with different electrolytical conductivity.

mS/cm (m mho/cm) 25°C	Plant reaction
0-2	Little reaction
2-4	The yield of salt sensitive plants may drop
4-8	The yield of salt sensitive plants drop
8-16	Only salt tolerant plants give high yield
>16	Only special salt tolerant plants give yields

The soil saturation extract = SSE gives a more stable reading than, for example, soil: water dilution of 1:2. Normally the SSE values are 4-5 times higher than 1:2 solutions, but a big problem is the variation in the later measurements. The most known way of making SSE is to stir water in soil to a heavy floating mass. The method described above has given satisfactory results without stirring. The problem is to add the right amount of water, which only can be learned through experience.

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Neutron Method of Soil Moisture Determination

Purpose: Neutron moisture probe is lowered into a vertically installed access tube to produce a moisture profile.

EQUIPMENT

The experience gained with the neutron moisture meter since the pioneering work achieved in the earlier years following 1950 (Belcher et al. 1951, Gardner and Kirkham, 1952) is already so important and diversified, that one is able to compare its actual state of development with that in the near future stating the desirable characteristics which an apparatus should have to carry out studies on soil water economy.

The principal of the neutron method of soil moisture determination is already well known (van Bavel et al 1956, Yemelyanov et al 1964). By way of introduction it suffices to recall that in a moisture containing medium, fast neutrons emitted by a radio-active source are first slowed down through elastic collision with H nuclei to thermal neutrons after covering an average slowing down length L_s of which $L_s^2 = \frac{1}{6} \frac{AB}{AB}$ (see fig. VII,1a).

The neutrons thus slowed down travel a certain distance called diffusion length L of which $L^2 = \frac{1}{6} \frac{BC}{BC}$ (see fig. VII,1a) until they are captured by the nuclei of the surrounding medium. Around the source, an equilibrium is reached nearly instantaneously among the neutrons emitted, between those scattered, slowed down and captured. It is observed that the density of the thermal neutrons around the source, at a sufficiently small distance from it, increases rapidly with an increasing number of hydrogen nuclei in the moderating substance.

Consequently when a probe, containing a fast neutron source and a detector, is lowered in a soil through an access tube, the number of thermal neutrons detected is a function of the moisture content (fig. VII,1b). This function is determined experimentally and called the calibration curve although in some circumstances (see Haahr and Ølgaard 1965) it is possible to calculate it.

The instrument to carry out the measurements is called a neutron moisture meter of which the essential parts are given in fig. VII,1a.

Desired characteristics of the neutron moisture meter for soil-water studies in the field

The reason why this method, even in its early stage of development appealed to a great number of soil scientists is, that by its nature, it offers the possibility of quick non-destructive measurements (+ 2 minutes) in situ with a portable instrument. This does not mean that yet all characteristics, necessary to make the neutron moisture meter an outstanding tool in scientific research are there. In order to reach this stage the following basic conditions must be met :

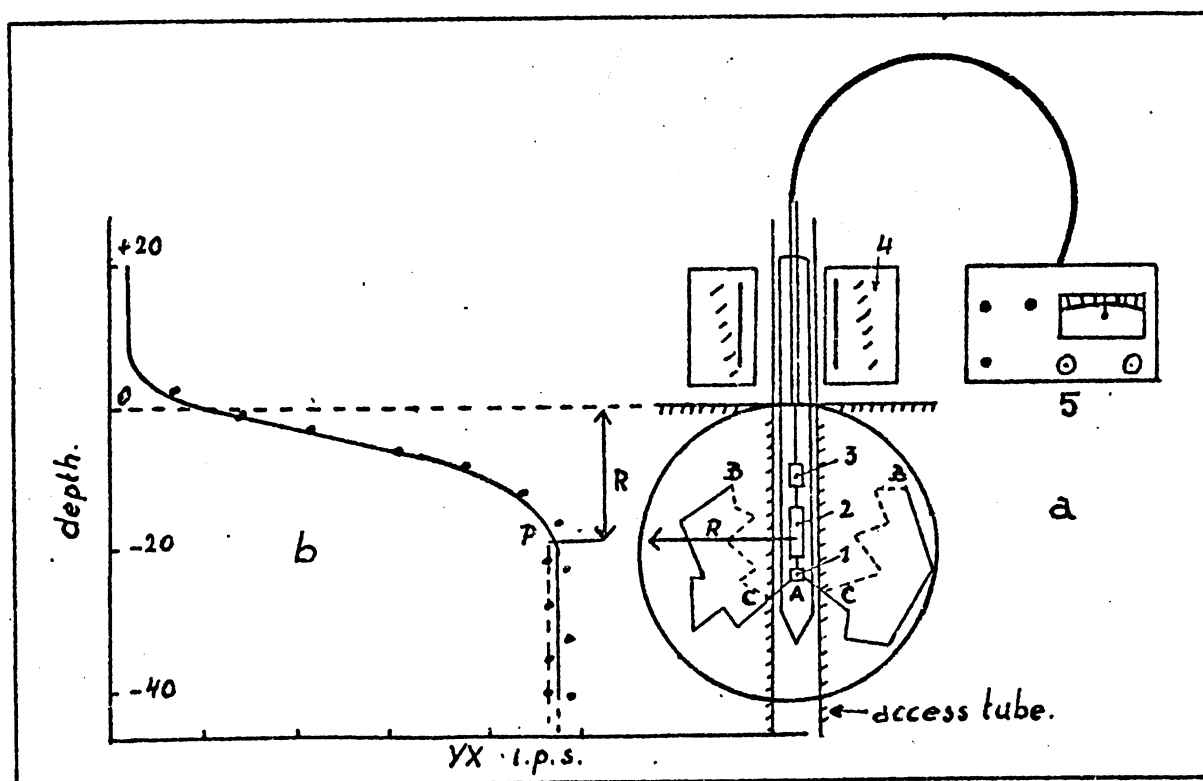


Fig. VII,1a

Neutron moisture meter with the essential parts : 1 : source
2 : detector 3 : preamplifier 4 : standard moderator being at
the same time the shield against radiation 5 : box containing
the power supply together with the count rate device.

Fig. VII,1b

Diagram showing the determination of the sphere of influence and the determination of its radius R.

- 1) the apparatus must be simple (light in weight and commodious to instal), reliable and easy to operate without danger.
- 2) the measurements must be accurate, precise, and quickly obtained.
- 3) the spatial resolution must be readily changeable from very small (the maximum allowed being the average thickness of an horizon \pm 25 cm) to large (the minimum being the average thickness of a normal soil profile \pm 80 cm).

4) PROCEDURE

The apparatus

The commercially available neutron moisture gauges are simple and easy to operate in such a way that they can be handled by technicians. However, the method is not devoid of difficulties and non-routine measurements should always be supervised by some one who is aware of all the factors involved. Characteristics of the instrument such as weight, ease of installation, reliability and health hazard are principally determined by the kind and strenght of the source. Therefore the source with its repercussion on the apparatus will be discussed first.

The classical sources to obtain fast neutrons are a mixture of alpha emitters and beryllium. Suitable sources should have a long halflife time together with a low natural gamma radiation. At the beginning radium-beryllium sources were used.

In table 1 (adapted from Andrieux et al. 1962) the characteristics of the most commonly used radio-active sources of fast neutrons are given. It is obvious that Ra-Be sources offers the greatest health hazard. Most suited are Pu-Be or Am²⁴¹-Be sources.

TABLE 1

Most commonly used radio-active sources of fast neutrons.
It is assumed that Beryllium be the target.

Radioact. source	T $\frac{1}{2}$	Energy α_2^4 in MeV	Cacul. En n_0^1 in MeV	Actual En n_0^1 in MeV	Neutron flux per curie	γ -rays
Po $^{210}_{84}$	138 d	5,3	6,7-11,01	1-10,8	300×10^4	negl.
Ra 226	1620 Y	4,78(93,5%) 4,59(6,5%)	6,04-10,49 5,85-10,30	1-13	1500×10^4	strong
RaD(Pb 210)	22 Y	5,298		0,5-9	250×10^4	weak
Pu $^{239}_{94}$	24,400Y	5,15(72,5%) 5,13(16,8%) 5,10(10,7%)	6,41-10,86 6,39-10,84 6,36-10,81	1-10,9	140×10^4	weak
Am $^{241}_{95}$	458 Y	5,44 5,48	6,70-11,15 6,74-11,19	1-11	220×10^4	weak

A promising idea for a safe neutron moisture meter comes from Yemeljanov (1963) who applied for a patent. The idea is to use encapsulated sources which emit neutrons or greatly magnify their output only when the components are positioned in a certain way. So in the "inactive" position the source would not emit any ionizing radiation at all outside the container. In this case the reliability (constant and reproducible output of the same neutron flux) of the source which is out of question in the other cases can pose a problem when no special precautions are taken e.g. by putting the probe in the standard moderator (see fig. VII, 1a). Based on a completely different idea is the generation of neutrons through a high voltage circuit. This has been realised in a very bulky instrument even on commercial basis (e.g. Philips) a few years ago. The latest information (not from a commercial source) is promising indicating that the unit can be made now of portable size. Here the ionisation hazard certainly can be brought back to a minimum. Besides that, within a certain range, it will be possible to vary the neutron flux as well as its intensity and hence the spatial change deliberately resolution (see further).

In the actual situation, a modern instrument with a 100 mC Am²⁴¹-Be source together with the standard moderating container (see fig.VII,1a) consisting of a shielding of cadmium, paraffin and lead, weighs + 20 kg. It allows for 40 hours a week field use when appropriately operated. It is reliable, easy to operate and relatively free of danger. The main drawback is the weight and the difficulty of installation in the field, the access tube having a diameter of 4-5 cm. The probe reduced to 1/2 of its actual size should greatly facilitate the work.

5) REMARKS

a. Accurate precise and quick measurements

By accuracy one understands the degree of conformity to the true value. Deviation from the latter are given in absolute percentage. Precision is the possibility of obtaining each time the same magnitude of a given value by repeated measurements. Experience tell us that the accuracy of the measurements is certainly as good as the one obtained with the most carefully executed gravimetrically determined moisture content. Van Bavel et al (1956), claim an accuracy of .5 %. Yemeljanov et al (1963) conclude that the error does not exceed 1,5 % by soil volume. Our experiments which consisted of repeated measurements of the same standards at time intervals of several weeks showed a precision of 0,75 volumetric %.

This means that to get a precision equal to that of a single measurement with the neutron meter, at least 7 gravimetric determinations are required.

The main errors (accuracy) however come from a misconception of the calibration curves and an underestimation of the spatial geometry probe-moderator. Experience indicates that calibration through simulation of a given volumetric moisture content through artificial mixtures in the laboratory does not yield the right results for field measurements. Simulating standards are only useful for comparing the characteristics of different neutron moisture gauges or for controlling the precision of one and the same apparatus at different periods of time. Such standards can be made of neutron moderators or of neutron absorbers or a mixture of both. Among the convenient mixtures of solids we cite :

alum and sand; paraffin and sand, sugar and sand. Among the liquid standard the two easiest to obtain are : boric acid or cadmium chloride. The first one is easy to obtain but the useful range is limited from about 8 to 35 percent moisture content by volume. Solid standards involve more labor but are more permanent.

The so called field calibration may not be understood in its simplified form. The latter means the relationship between counting rate and moisture content as obtained by installing access tubes in natural soils without taking into account the heterogeneity of both soil and moisture in the profile. The minimum number of samples to be taken on each depth in an homogeneous layer (called horizon) is seven. When no horizons are taken into account 50 samples might be necessary to get a good average.

The spatial geometry probe-moderator is so critical that a deviation of 1 mm in distance between both results in a noticeable error as can be seen from fig. VII,2. Holes and logs along the access tube must be avoided. Erroneous results are obtained when access tubes remain at the same spot for several months and water infiltration occurs along the access tube !

Other factors affecting the calibration curve are soil density, the presence of crystal water and of neutron absorbers. It is obvious that the fast neutrons are also slowed down partly through inelastic collision with the nuclei others than hydrogen. On the other hand due to the work of Mortier and De Boodt (1954) it is known that crystal water in the clay lattice contributes also to the slowing down of the fast neutron although not in the same proportion as free water (Yemelyanov 1963). So it is obvious that the density should be taken into account; in light soils only one factor is involved but in heavy soils there are two. Independant research in Belgium, Denmark and Russia indicate the same order of magnitude for the influence of density. In sandy material and moraine clay a deviation of the density of the dry soil of $0,1 \text{ g/cm}^3$ results in an error in the water content of respectively $\pm 0,5$ and ± 1 vol. %.

Concerning neutron absorbers, it is remarked that in agricultural soil, chlorine is the most important. From the work of Damagnez (1962) it can be inferred that the presence of 1 g NaCl per 1000 cm^3 (1000 ppm) results in an error at high water content of $\pm 1\%$.

CALIBRATION CURVES AS INFLUENCED BY THE CHANGING DISTANCE ; PROBE-MODERATOR.

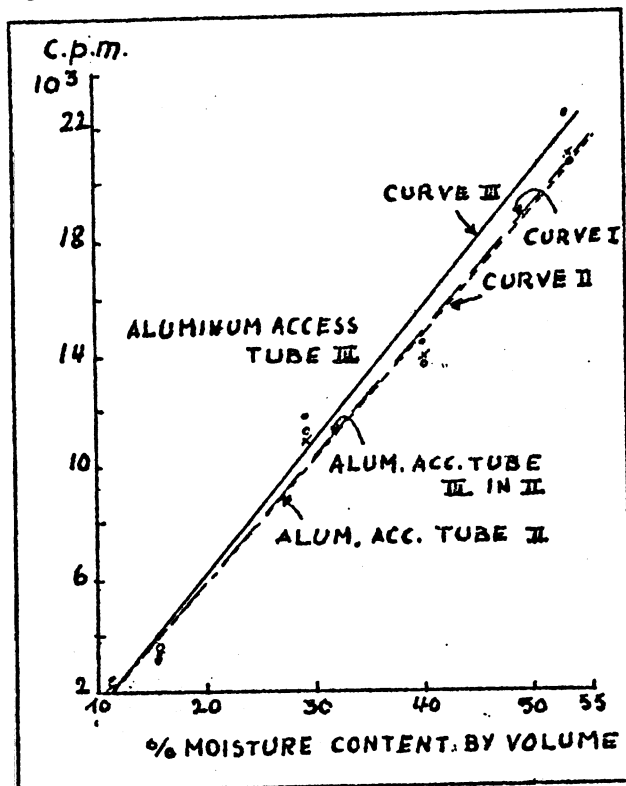


Fig. VII,2

Figure showing three calibration curves of which two (I and II) practically coincide; curve III shows a marked difference with the two others because of a difference of 1 mm in distance between the moderator and the probe. In this experiment two aluminium access tubes one fitting perfectly in the other were used, so three combinations were possible to study the geometry influence. Curve III is obtained when using the smallest tube; curve II when using the largest tube (1 mm difference in outer radius) and curve I when using the smallest tube inserted in the largest.

In fig. VII,3 the differential influence of the factors mentioned here are given. To carry out good work, calibration in the laboratory with homogeneous soils of known density covering a volume of 1 m^3 to satisfy the limit conditions is nevertheless necessary to get at least one "master" calibration curve.

When one is only interested in differences in moisture content, one should use only differences in counting rates and compare it with the "master" calibration curve. So covariance eliminates part of the errors due to disturbing effects in geometry etc... An extensive discussion on the accuracy of the method is given by Hewlett et al (1964).

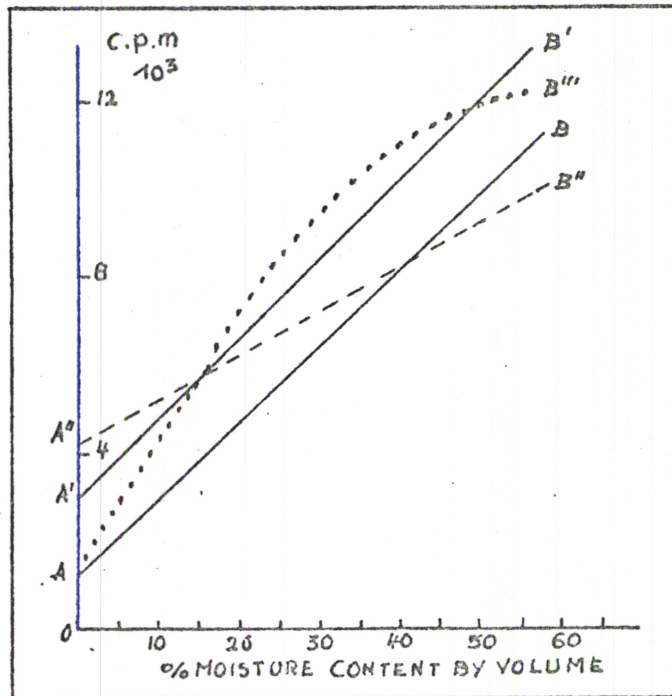


Fig. VII,3

Relative positions of the calibration curves :

The "master" calibration curve AB is shifted over a distance AA' but the slope stays the same (see curve A'B') when the density of the medium increases. However the inclination of the curve changes markedly (see curve A''B'') through the presence of neutron absorbers or by changing geometry in the spatial arrangement source-moderator (see curve A'''B''').

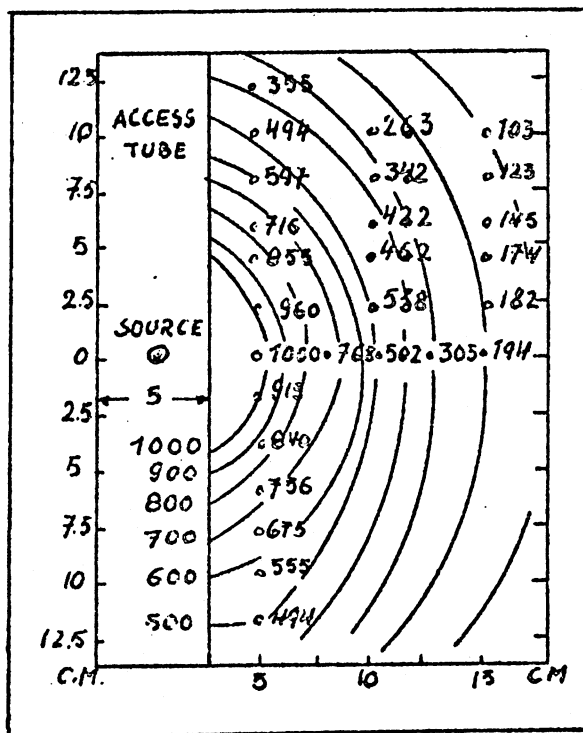
b. The spatial resolution

The sphere of influence pertaining to a given source-detector assembly is measured as shown in fig. VII,1b where R is the radius of the sphere around the source which contains 95 % of all thermal neutrons. By definition this sphere is called the sphere of influence (van Bavel et al 1956).

At first glance obtaining an average moisture content through the neutrons scanning a large volume, thus working with a large sphere of influence seems the easiest to realize as it is inherent in the method. Indeed, the first workers with the neutron moisture meter observed a diameter for the sphere of influence varying from 30 cm to 140 cm for soil moisture contents varying from 100 per cent to 1 per cent by volume. This seems to fulfil quite well the first requirement and for practical purposes it does. However in theory a serious objection may be formulated. As can be seen from fig. VII,4 the hydrogen ions closest to the source detector assembly contribute most to the number of counts (Mc Henry 1963). The second aspect namely the reduction of the sphere of influence has been the object of a great deal of research.

Fig. VII,4

The distribution of slow neutron densities in water around the access tube containing a fast neutron source. The recorded neutron densities are the relative observed number of pulses in a vertical section 2,5 cm thick. Remark the quick decreasing contribution of each layer as the distance from the source increases (after Mc Henry 1963).



As the distance travelled by the neutrons is composed of the slowing down length L_s and the diffusion length L it is obvious that the reduction of the sphere of influence can be obtained through diminishing one of these factor or both. In water $L = 2,72$ cm and $L_s = 6,8$ cm. The diffusion length L can be made equal to zero by measuring not thermal but epithermal neutrons. This can be realised by protecting the detector with a foil of cadmium or a layer of hydrogen containing substances which capture the thermal neutrons. In such a case the detector is only reached by the original epithermal neutrons slowed down to thermal neutrons after passage through the shielding coat. The other possibility is working on the slowing down length. The diminution of the slowing down length L_s can be realized in two ways :

- 1) Using an auxiliary moderator (hydrogen containing substance) put around the source. De Boodt (1964) found that in this respect the optimal thickness of the auxilliary moderator around the source is obtained when using a 3 to 4 mm thick layer. With neutrons, generated electrically, it is possible to change their energy level and hence the penetrating power in the moderating substance.
- 2) To measure directly the flux of epithermal neutrons (± 1 ev) or even intermediate neutrons (± 100 ev) around the source instead of thermal neutrons. Experiments by Moerman and De Boodt (1966) show however that although this is theoretically possible by using He_3 counters, the cross-section of the epithermal and intermediate neutrons is insufficient to obtain a sufficient flux. However as can be seen from fig. VII,5 the discrimination of the He_3 counters for γ rays and the sensitivity to thermal neutrons is very good. So this detector surrounded with a cadmium foil but open in the center can be used to make the sphere of influence more elliptic. The combination of an auxiliary moderator around the source together with a protected detector over all parts yielded an ellipse of influence of which the height is 18 cm in water and 40 cm in a soil containing 11 % moisture by volume. Although this is not yet considered to be the ideal,

the progress is promising. As can be seen from Table II mainly composed from the work done by Mortier and De Boedt (1960, 1961, 1964) and also by Kühn (1959) many combinations are possible resulting in a marked improvement of the resolution since the method started about + 15 years ago.

NEUTRON SPECTRUM AS MEASURED WITH A He³ DETECTOR.

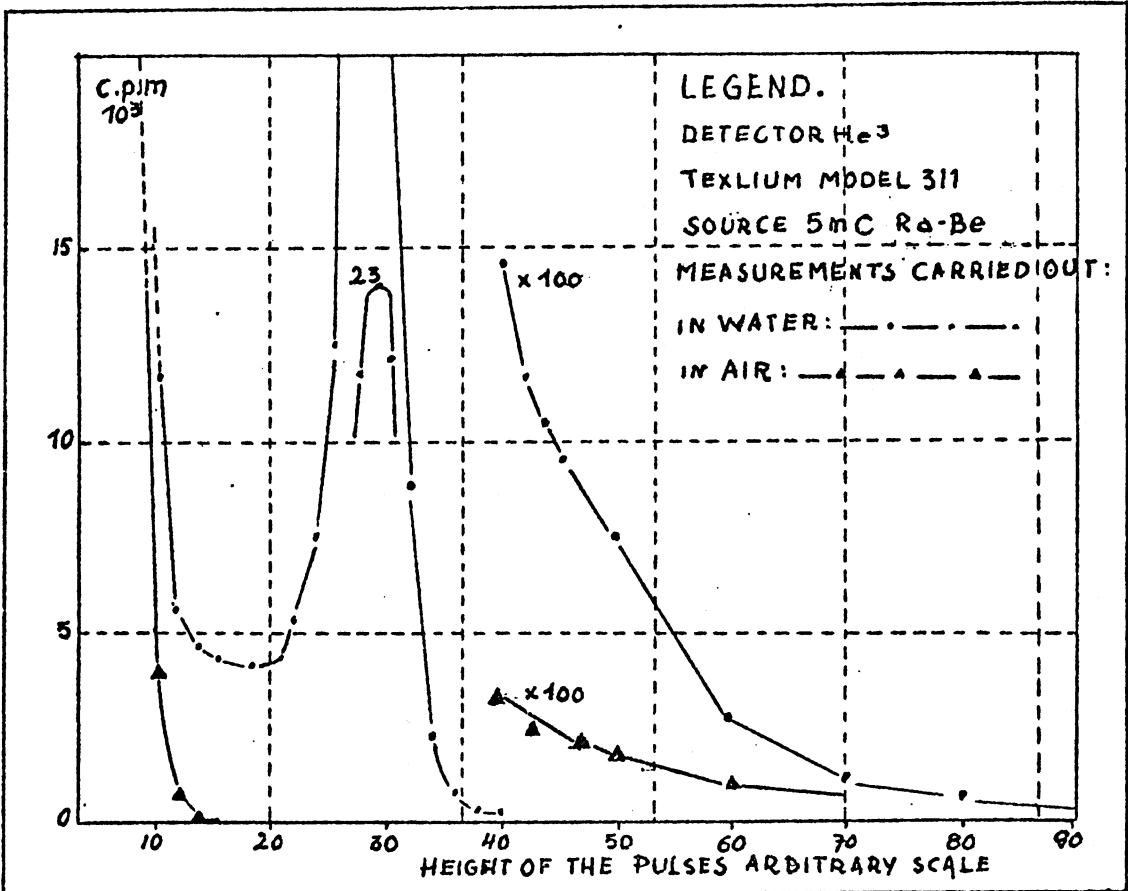


Fig. VII,5
 Neutron spectrum realised when the 5 mC Ra-Be source is located at the centre of the He³ counter; high voltage 1300 V; window 2 V; time constant 1,6 μ sec. The γ pulses have a height 20 V, so the discrimination with the thermal neutrons having a mean height of 29 V is very good. The efficiency gained by measuring thermal neutrons with a He³ counter in stead of measuring with a BF₃ counter is 30 % (after P. Moerman).

TABLE 2

Radii (cm) of the spheres of influence observed by Mortier and De Boodt with different experimental arrangements.

Description of experimental arrangements	Moisture content by volume		
	Sand-K alum	K-alum	Water
	10,5 %	45,5 %	100 %
1. 50 mC Ra-Be surrounded with In-cylinder, \varnothing 3 cm, L 3 cm	21	16	10
2. 50 mC Ra-Be embedded in paraffin cylinder, all envelopped by In-foil	13	10	8
3. Four 5 mC Ra-Be sources, centre placement, micro $B^{10}F_3$ counter (2,5 cm long)	20	13	10
4. idem Cylindrical perspex probe (H-content 8 % by wt.)	14	10	8
5. idem Cylindrical polyethylene probe (H-content 14,3% by wt.)	16	14	10
6. 20 mC Ra-Be, end placement. Micro $B^{10}F_3$ Cyl. polyeth. probe (H-cont. 14,3% ...)	20	17	14
7. idem. $B^{10}F_3$ counter (15 cm long)	25	20	14
8. 5 mC Ra-Be scintillation crystal, embedded in paraffin. Kühn (1959)	20	17	14
9. 100 mC Am^{241} source, scintillation crystal distance between the two 9 cm	25	23,5	22,5

The combinations as mentioned in 7 and 9 (table 2) represents the performance of the majority of the actual commercial available moisture gauges. The most striking improvement is obtained when using indium foil as detector. In fact resonance epithermal neutrons of 1,4 eV are measured that way. The drawback of this method is that the activity of the foil has to be measured separately. Results of nearly equal quality are obtained when using a micro BF_3 counter. Here care must be taken to avoid piling up to the counts. Therefore preference is given to a sensitive He^3 counter, completely covered with cadmium except the centre where 2,5 cm free space exists. In table 2, no account

is given about the sensitivity of the method which is defined as $\frac{dn}{n} / \frac{dv}{n}$. A marked reduction of it is experienced when the hydrogen auxiliary moderator becomes too thick (> 4 mm).

c. Conclusion

For the moment, the method for determining soil moisture content through neutron scattering is in a state of evolution. As is pointed out marked improvements in the instrumentation may be expected in the near future. In general the three desired characteristics mentioned will than be fulfilled except perhaps the spatial resolution in relative dry soils. As long as this latter point is not solved, surface moisture probes do not make much sense in soil moisture studies for agricultural purposes as this instrument indicates average values for a relative large upper layer and not moisture gradients ! The latter near the surface being of utmost importance.

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