Preliminary remarks on porosity of soil aggregates in an air-dry state and at pF 2

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Summary

For a pycnometer determination of the pore volume of air-dry soil aggregates, size about 2—5 mm, kerosine was preferred over sand or mercury. It could be shown, that at pF 2 the pore space percentage of aggregates can be calculated from the water content under the assumptions that no air is present and that the pore space in the dry aggregates is too small to contain this amount of water.

On light soils the dry aggregates were only slightly denser than core samples under field conditions, and swelling percentages are small. On heavy soils dry aggregates were extremely dense. Here swelling properties and size of the aggregates are likely to be important aspects of soil structure.

1. Introduction

The strength of soil aggregates is known to be largely dependent on their water content (KUIPERS, 1959 a). Their porosity is likely to be another important factor. For this reason an investigation was started on the pore space of soil aggregates. It was found, that for sufficiently wet aggregates this could be calculated satisfactorily from their water content if pore space in a dry condition is relatively low.

2. Porosity of air dry soil aggregates

Three pycnometer methods were used in the course of the investigation to determine the volume of aggregates of the fraction 3,4—4,6 mm. From this volume and the weight of the air-dry aggregates the pore space inside the aggregates is calculated with the aid of determinations of the true density of the soil and of the water content in the air-dry state.

a. With *mercury*, according to STRICKLING (1950, 1955)

Pycnometers with a known quantity of air-dry aggregates are brought into a vacuum exsiccator which is evacuated. At an air pressure of about 0,02 atm. mercury from a container flows into the bottles till the aggregates, which are prevented from floating, are immersed. After opening the exsiccator the bottles are filled entirely. The volume of the aggregates equals the difference between the volume of the bottle and that of the mercury added.

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b. With *sand*

A calibrated tube (diam. 1,5 cm, length 10 cm) with a certain amount of dry, pure sand is vibrated for a few seconds to get a reproducible density. The volume of the sand in this state is determined from e.g. 5 repetitions. A known weight of aggregates is mixed through the sand and the volume of the mixture is determined in the same way. The increase equals the volume of the aggregates.

c. With *kerosine*, according to McINTYRE and STIRK (1954)

Pycnometers with a known weight of aggregates are filled with kerosine at an air pressure of about 0,02 atm. to prevent the entrapment of air. The kerosine inside the aggregates is determined by applying a suction force of 3 cm kerosine to a porous plate on which the aggregates are lying without touching each other. At this suction no air will enter the aggregates. The volume of the aggregates equals the difference in volume between the bottle and the kerosine added, corrected for the kerosine inside the aggregates.

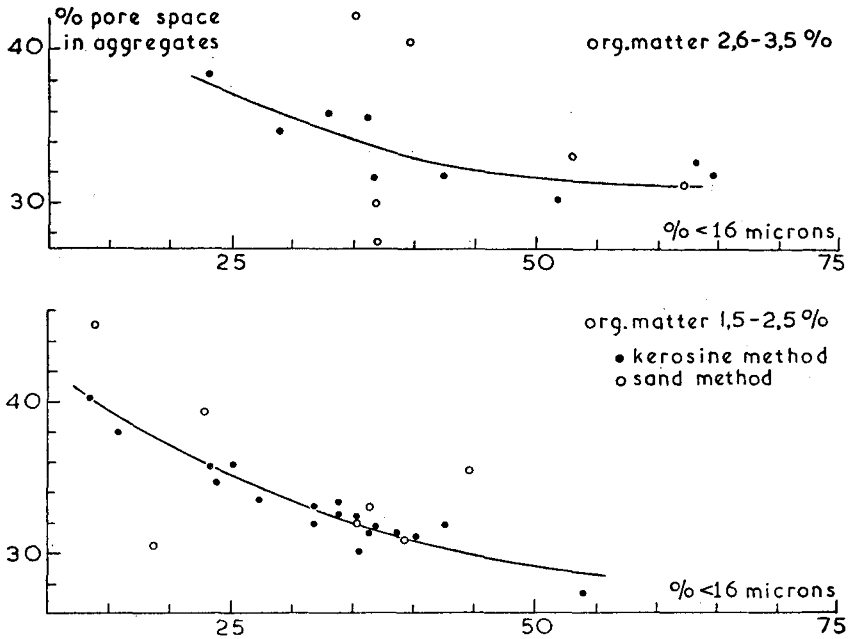
TABLE 1. Pore space percentage inside air-dry aggregates according to different methods

	Mercury	Sand			Kerosine
		Set 1	Set 2	Set 3	
	28,1	34,3	34,6	34,0	31,9
	26,6 *	33,1	31,8	34,0	32,5
	25,8	32,6	32,0	33,6	32,0
	26,9 *	29,9	31,0	32,9	31,4
	26,9	32,9	31,3	33,6	31,6
	30,4	33,6	30,5	32,6	32,2
	27,7	30,6	32,0	33,1	
		30,4	33,9	33,6	
		29,9			
Mean of sets		31,9	32,1	33,4	
Mean	27,5		32,5		31,9

* Corrected for mercury inside aggregates.

TABLE 1 shows the results of a comparison of the three methods for a rather light marine soil (particles smaller than 16 microns: 36,5 %, org. matter: 1,9 %). The determinations with mercury give low porosities. Some mercury was found inside the aggregates. Only in two cases a correction was possible. Probably determinations under atmospheric air pressure would give higher results. SUNKEL (1960) recently developed an apparatus based on this principle. In our investigation this method was abandoned as for the difficulties experienced in handling the mercury.
The results for sand and kerosine in TABLE 1 are about the same. As small cavities in the surface of the aggregates will not be filled entirely by the sand, with this method relatively high porosities were expected. For kerosine the same might be true as perhaps some surface cavities will not be emptied by the suction force of 3 cm kerosine.
In FIG. 1 the results of determinations on samples of 27 soils devided into two organic matter groups, are plotted against the clay content of the soil. There is a

FIG. 1. Relation between pore space percentage in air-dry aggregates and clay content of 39 soils divided into two groups with different organic matter contents. Determinations with sand and kerosine.



distinct negative correlation in both groups. In the group with high organic-matter contents pore space is somewhat higher than in the other one. With open circles the results of determinations with sand on twelve other soils are indicated. As there were not so many replicates as in the example of TABLE 1, the values may be expected to be less accurate. There is an indication that the circles tend to lie above the lines. The general agreement, however, was considered to be sufficient to accept the convenient kerosine method for routine determinations.

In FIG. 2 the pore space percentage inside air-dry aggregates of 23 marine soils in northern Groningen with different clay and humus contents (partly the same soils as in FIG. 1) is compared with the results of core samples under field conditions of a set of 88 soils of the same district (KUIPERS, 1959 b). Two details should be noted:

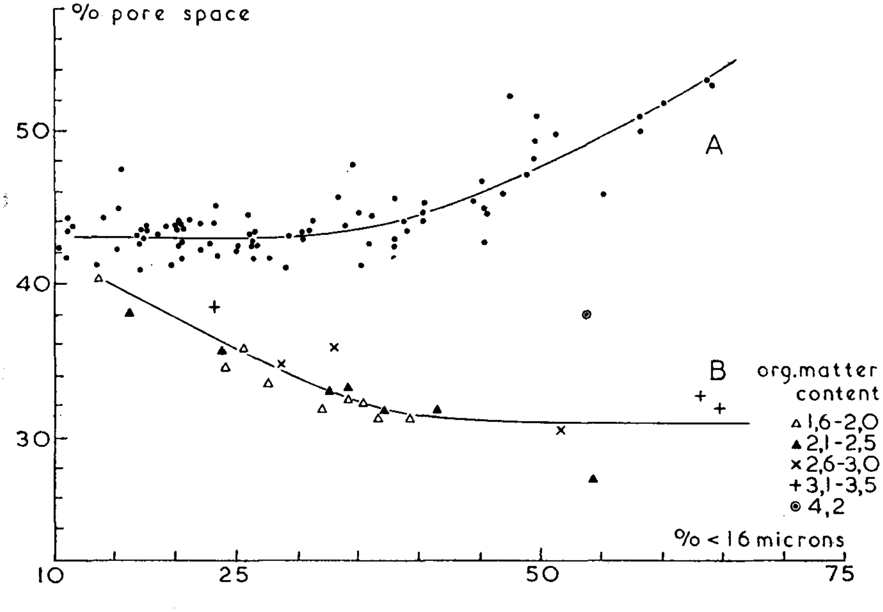
1. As in FIG. 1 there is a distinct negative correlation between pore space in the air-dry aggregates and clay content. With core samples taken from the field at higher moisture contents however the reverse is found.
2. Pore space percentage in the air-dry aggregates is extremely low on the heavy soils as compared with that of the core samples.

As compared with the figures given by STRICKLING (1950, 1955) there is a rather good agreement with regard to the absolute values. STRICKLING however found a positive correlation with silt and clay content. This may be due to the fact that he got his soils from only one experimental field.

FIG. 2. Relation between pore space and clay content of marine soils from northern Groningen :

(A) for core samples of 88 soils under field conditions.

(B) for air-dry aggregates of 23 soils with indication of the organic matter content.



3. Porosity of aggregates at pF 2

Wet soil aggregates are too weak for applicating the methods described above. If the increase in volume due to swelling could be measured, pore space in the wet condition could be estimated. This however appears to be very difficult. Two approximations could be obtained from other experiments.

a. Cores (diam. 3,6 cm ; height 5 cm) were filled with air-dry aggregates of the fraction 3,4—4,6 mm. A reproducible rather close packing was obtained by vibrating. The samples were wetted at an air pressure of about 0,02 atm. to avoid desintegration and then brought at pF 2. The height of the samples was measured in the dry state and at pF 2 in tenths of millimeters. From these figures a linear swelling percentage is calculated. The lateral confinement will tend to increase the results of these calculations at high swelling percentages. The possibility of reducing the pore space between the aggregates however will have the reverse influence. This should be expected to be important at low swelling percentages. The figures thus found will be referred to as the "experimental" values. They should be regarded as a rough approximation.

b. Of the aggregates studied, water content at pF 2 was known. There is no reason to expect the water between the aggregates to be of any importance (KUIPERS, 1961). A simple calculation learns that if the water is stored inside the aggregates,

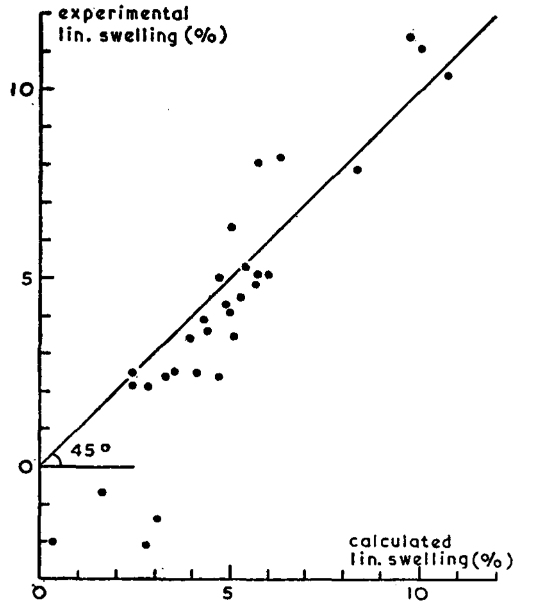


FIG. 3. Relation between experimental and calculated linear swelling percentages for 30 marine soils

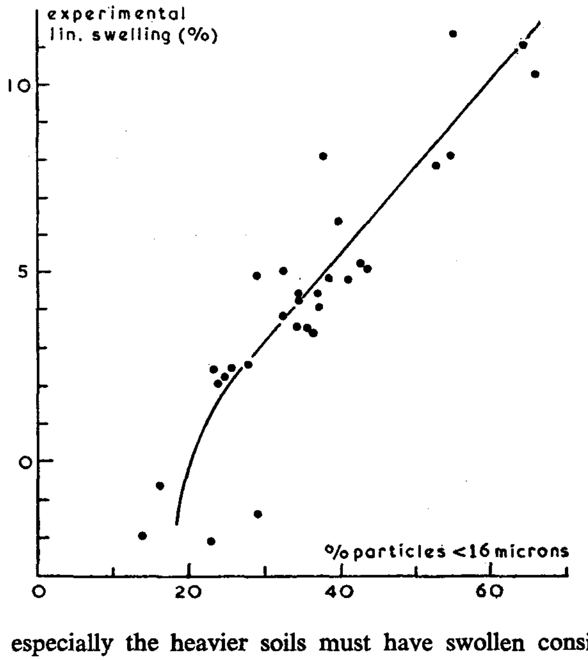


FIG. 4. Relation between linear swelling percentage observed and clay content for the same soils as used in FIG. 3.

especially the heavier soils must have swollen considerably. It is not to be expected that in this case there will be air voids in the wet, relatively small aggregates. So the linear swelling percentage can also be calculated from the difference between the volume of water held at pF 2 and the pore space in the dry state. These figures will be referred to as the "calculated" values.

The experimental and the calculated values are plotted in FIG. 3 for a set of 30 marine soils. At the lower end the points indeed tend to lie under the line of perfect agreement. Here even negative experimental values are found. As is demonstrated in FIG. 4 this is only the case on very light soils. The aggregates of these soils are destroyed easily and this will be the cause of the negative values. Generally speaking the agreement in FIG. 3 is so good that the calculation of the pore space at pF 2 in aggregates of a few millimeters from their water content and under the assumption that no air voids will be present, can be accepted as a reasonable approximation. It will be clear however that applying this method the pore space of the aggregates in the dry state must be too low to store the water held at pF 2.

4. Conclusion

In light soils there was a minor difference between the pore space in core samples and in air-dry aggregates. Also the moisture content has a small influence on pore space. So aggregation in light soils should be expected to have a less distinct character than in heavy soils. In the latter the aggregates were so dense, that little influence of the mechanical forces used in agricultural practice is to be expected on the density of the aggregates examined. As aggregate size and arrangement will influence the ability of the aggregates to swell, these aspects are likely to be important here.
In case of heavy soils moisture content and density of soil aggregates appeared to be so closely related that it may prove impossible to distinguish between the influence of either on the strength of aggregates.

LITERATURE

KUIPERS, H. 1959a Confined compression tests on soil aggregate samples. *Meded. Landbouwh.school en Opzoekingsstations v. d. Staat te Gent.* Deel 24 No. 1, 349—357.

—— 1959b Some remarks on pore space and pressure on marine clay soils. *Meded. Landbouwh.school en Opzoekingsstations v. d. Staat te Gent.* Deel 24 No. 1, 392—397.

—— 1961 Water content at pF 2 as a characteristic in soil cultivation research in the Netherlands. *Neth. J. agric. Sci. 9,* 27—35.

MCINTYRE, D. S., and G. B. STIRK 1954 A method for determination of apparent density of soil aggregates. *Austr. J. Agric. Research. 5,* 291—296.

STRICKLING, E. 1950 The effect of soybeans on volume weight and water stability of soil aggregates, soil organic matter and crop yield. *Soil Sci. Soc. Amer. Proc. 15,* 30—33.

—— 1955 Relationship of porosity to water stability in Beltsville soil aggregates. *Soil Sci. 80,* 449—458.

SUNKEL, R. 1960 Über die Porosität von Bodenaggregaten. *Zeitschr. Pfl.ernähr. Düngung Bodenk. 89* (134), 17—27.