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AN ATTEMPT TO CHARACTERISE SOIL MACROPOROSITY ON THE BASIS OF STRUCTURE STANDARDS

M. Bryk, H. Domżał, J. Pranagal, A. Słowińska-Jurkiewicz

Institute of Soil Science and Environment Management, University of Agriculture in Lublin
Króla Leszczyńskiego 7, 20-069 Lublin, Poland

Abstract. The aim of this work was to characterise macroporosity of soil preparations by means of image analysis. Preparations were made from the samples taken from 0 – 20 cm layer of four types of soil: typical soil lessivé developed from loess, proper rendzina developed from cretaceous marl, chernozemic rendzina developed from chalk and mud-gley soil developed from clayey silt. The values of porosity by image analysis, P_K, (pores of the diameter greater than 200 μm) were compared with the values of field air capacity, (P_{PP}, pores greater than 20 μm) and total porosity, determined by classical methods used in soil science. For most of the samples porosity obtained by computer image analysis, P_K, was lower than the values of field air capacity, P_{PP},, as expected. For the rest of standards, the values obtained morphometrically, P_K, were higher than P_{PP}. It probably resulted from unequal pore sizes in the dried and moistened soil material and innate attributes of the method of soil water desorption. Statistical analyses revealed strong, statistically valid dependencies, with high values of the correlation coefficients (0.883 – 0.951) between porosity, P_K, total porosity, P_O, and field air capacity, P_{PP}. Moreover, correlation indices calculated for P_O and P_{PP} confirmed the already known relation.

Keywords: soil macroporosity, morphometric analysis, structure standards, computer image analysis.

INTRODUCTION

Soil porosity influences its water and air properties. Estimation of porosity helps to evaluate changes in the soil, caused by various types of mechanical soil treatment and stresses to the soil induced by movement of heavy machinery and agricultural tools as well as the influence of meteorological factors, amelioration, substances promoting structure formation, etc. [1]. Macroporosity is an important indicator of space available for root elongation and easy cycling of air and water in the moist ("field capacity") state [2].

Comparison of porosity determined by morphometric analysis with volumetric water retention data was made by many researchers in relation to various aspects of the case. Most of the papers concerned, however, soil samples with preserved natural soil structure [2]. On the basis of granulometric composition expressed as the proportion of the number of soil particles in various size classes (except for clay), Czachor [3,4] has modelled numerically the so-called virtual soil structure. For the particle set (aggregate) made as a system of rigid spheres, he determined porosity and examined the "soil moisture – soil water potential" curve.

In the present work, we show, by contrast, a model research based on soil preparations - soil structure standards - made of aggregates (0.25 - 10 mm in size) separated from natural soils. The scope of this work was to evaluate porosity of those structure standards by means of morphometric analysis, and to compare the results with the porosity values obtained by other, classical soil science methods.

MATERIALS AND METHODS

Samples were taken from the 0 – 20 cm layer of four soils: typical soil lessivé developed from loess (Huta Turobińska, Lublin Upland; cultivated field), proper rendzina developed from cretaceous marl (Nowy Dwór, Lublin Upland; cultivated field), chernozemic rendzina developed from chalk (Sielec, Volhynian Polyesie; cultivated field) and mud-gley soil developed from clayey silt (Tarnawka, Lublin Upland; meadow). The samples with disturbed structure were kept at the room temperature until air-dry and afterwards sieved through a set of sieves in order to separate the fractions of aggregates measuring: 10–7, 7–5, 5–3, 3–1, 1–0.5, 0.5–0.25 and below 0.25 mm. The aggregates separated this way were dried at room temperature and then poured into metal boxes (8×9×4 cm in size) and standard Kopecky's cylinders of 100 cm^3. Soil aggregates from each class were not intentionally compacted. The samples prepared in metal boxes were impregnated with a solution of polyester resin according to the method described earlier [5-7]. Soil structure preparations were marked in the following way: typical soil lessivé - HT, proper rendzina - N, chernozemic rendzina - S and mud-gley soil - Ta. Ranges of aggregate sizes in the samples were given in the subscript.

Hardened preparations were cut into 1 cm-thick plates. For each hardened block, there were obtained four, for several three ($S_{0.5-1}$, $HT_{0.25-0.5}$), two ($N_{0.5-1}$, $Ta_{0.25-0.5}$) or one ($N_{0.25-0.5}$) plane for analysis.

Opaque block planes were acquired by a computer image analyser imager-512. The pictures in 256 shades of grey and binary images were prepared. Binary images were subjected to morphometric analysis, using a computer programme

IMAL-512. The cross-sectional area of the soil aggregates was measured. The sum of aggregate sections and the total area of the opaque block plane were calculated. According to these results, principles of stereology and planar estimator of volumetric porosity, porosity of the soil structure standards, P_K, was determined [8,9]:

$$P_K = \frac{A_Z - \Sigma_{i=1}^{n} A}{A_Z} 100\% \qquad (1)$$

where: P_K - porosity by morphometry (%); A_Z - area of the opaque block plane (mm^2); $\Sigma_{i=1}^{n} A$ sum of the aggregate cross-sections for a given plate (mm^2).

Total porosity, P_O, was calculated, for a given soil particle density and bulk density of each aggregate fraction. Soil particle density was determined by the pycnometric method. Soil bulk density was calculated as the ratio of the mass of the dried soil material (105 °C) in a Kopecky cylinder to its volume (100 cm^3).

Field air capacity, P_{PP}, was calculated on the basis of total porosity and field water capacity (pF=2.0; –9.81 kPa), determined by the Richards' method of water desorption in low-pressure chambers on ceramic plates.

In order to investigate the possibilty for the existence of statistically confirmed relations between P_O, P_K and P_{PP}, correlation coefficients were determined by a computer programme arstat - "core.exe" at confidence level α=0,05. The results were presented in the graphs as the function $P_O(P_K)$ and $P_{PP}(P_K)$.

RESULTS AND DISCUSSION

The results of our research, i. e.: porosity by image analysis, P_K, total porosity, P_O, and field air capacity, PPP, are presented in Table 1.

Total porosity, P_O, of all the preparations was in the range of 60–70 (%, v/v). The preparations obtained from the soil lessivé had porosity from 60 to 65 (%, v/v). That porosity showed an increasing tendency as the diameter of the aggregates in the samples declined. Quite a different situation was observed for the proper rendzina. In this case, total porosity decreased from 67.7 to 61.4 (%, v/v). A similar tendency was demonstrated for the chernozemic rendzina where porosity ranged from 58.4 to 67.8 (%, v/v). All the samples of mud-gley soil were characterised by comparable values of porosity, varying in the range of 67.9–71.3 (%, v/v).

As for the porosity derived from image analysis, P_K, for the standards made of soils designed as N, S and Ta, one could detect a common tendency: for the first

T a b l e 1. Total porosity, P_0 (%, v/v), porosity by morphometrical analysis, P_K (%), field air capacity, P_{PP} (%, v/v). Results were given in bold type-face for $P_K > P_{PP}$

Parameters	Soils											
	HT - typical soil lessive developed from loess						N - proper rendzina developed from cretaceous marl					
Aggregate sizes (mm)	10-7	7-5	5-3	3-1	1-0.5	0.5-0.25	10-7	7-5	5-3	3-1	1-0.5	0.5-0.25
P_0 (%, v/v)	61.1	60.3	61.5	62.6	64.1	64.5	67.7	67.7	67.7	66.5	66.1	61.4
P_K (%)	21.4	23.4	27.4	37.5	37.5	19.0	39.0	40.2	33.3	40.6	20.0	12.5
P_{PP} (%, v/v)	22.9	21.7	33.5	39.0	27.3	22.8	37.5	37.0	38.8	35.4	32.0	22.1
	S - chernozemic rendzina developed from chalk						Ta - mud-gley soil developed from clayey silt					
Aggregate sizes (mm)	10-7	7-5	5-3	3-1	1-0.5	0.5-0.25	10-7	7-5	5-3	3-1	1-0.5	0.5-0.25
P_0 (%, v/v)	65.5	67.5	67.8	67.1	62.7	58.4	70.8	71.3	69.9	67.9	69.9	70.4
P_K (%)	37.1	33.0	29.7	34.8	9.1	16.2	36.2	29.7	29.8	34.0	18.6	15.0
P_{PP} (%, v/v)	32.1	36.1	36.4	34.2	30.0	17.7	34.5	36.2	34.1	29.8	28.1	20.4

four preparations (range of aggregate diameters of 10-1 mm) porosity fluctuated in the range 30-40 %, and for the last two samples (aggregate diameters from 1 to 0.25 mm) it decreased to 10-20 %. A slightly different situation was noticed for the soil lessivé; porosity of the preparations made of aggregates 10-1 mm in size increased from 21.4 to 35.7 %, and then decreased to 19 % for the standard made of aggregates in the range of sizes 0.2-0.5 mm.

For the field air capacity, P_{PP}, a similar, common, course of value changes for this parameter was seen in the samples made of chernozemic and proper rendzina and mud-gley soil. Field air capacity, P_{PP}, increased only slightly and oscillated around 35 (%, v/v), while the aggregate diameter in the samples decreased to about 20 (%, v/v) for the preparations made of aggregates of even smaller diameters. For the soil lessivé one could discover much lower values of the field air capacity for the samples labelled HT7–10 and HT5–7, 21.4 and 23.4 (%, v/v), respectively. The remaining results were similar and showed a similar tendency as for other soils.

Field air capacity is defined as the volume of macropores in the soil, i.e. empty spaces larger than 20 μm in size. Resolution of the computer apparatus let us determine objects greater than 200 symbol 10 μm. That is why we concluded that the porosity obtained by computer image analysis, P_K, should be smaller than the values of field air capacity, P_{PP} (volume of macropores). For more than a half of cases such a relation was in fact detected. For the rest of samples, values of porosity obtained by morphometrical analysis, P_K, were slightly higher than P_{PP}. It was probably caused by unequal pore sizes in dry and wet soil. From the soil water desorption curve used to determine field air capacity, we could obtain the smallest pore sizes. Their diameters were decreasing due to the layers of water adsorbed on their walls. The relation "soil water potential – soil moisture" shows a hysteresis loop. For the state of water adsorption a certain volume of water is contained in the pores of greater diameters than the diameters of pores containing the same volume of water for the state of desorption [10]. On the contrary, morphological analysis of the structure is based on the opaque blocks made of dried soil.

Another possible explanation of the differences between the results was that the maximum cross-sectional area (which is the basis for the estimation of pore volume) of pores was measured by the morphometrical analysis. On the other hand, determination of pore diameters and volumes by desorption of water from the soil samples is based on the principle that the force with which water is retained in a pore depends on its diameter, assuming that pores constitute a continuous system and have approximately cylindrical shapes. For that reason, the method of soil water desorption gives information about the smallest exits of a pore rather than about pore diameter itself [2].

Moreover, the determination of pore diameters and the volumes by the method of soil water desorption is based on the assumption that pores constitute a continuous system and are approximately cylindrical. It is common knowledge that soil pores between single grains of soil material as well as between soil aggregates can only roughly correspond to this ideal model. Soil pores often are of bottle-like shape. During water desorption, part of it may be retained in the pores which have no connection with the exterior of the soil sample and in the pores with exits not broad enough. In consequence, the water of a specific potential cannot be removed from such pores. It caused the reduction of value of field air capa-city, P_{PP}, in comparison to the porosity determined by image analysis, P_K.

Statistical analysis was made confirmed statistically valid relations (Figs 1 and 2), with high values of the correlation coefficients (0.883 - 0.951) between porosity, P_K, total porosity, P_O, and field air capacity, P_{PP}. Moreover, correlation index calculated for P_O and P_{PP} (0.951) confirmed the known relation.

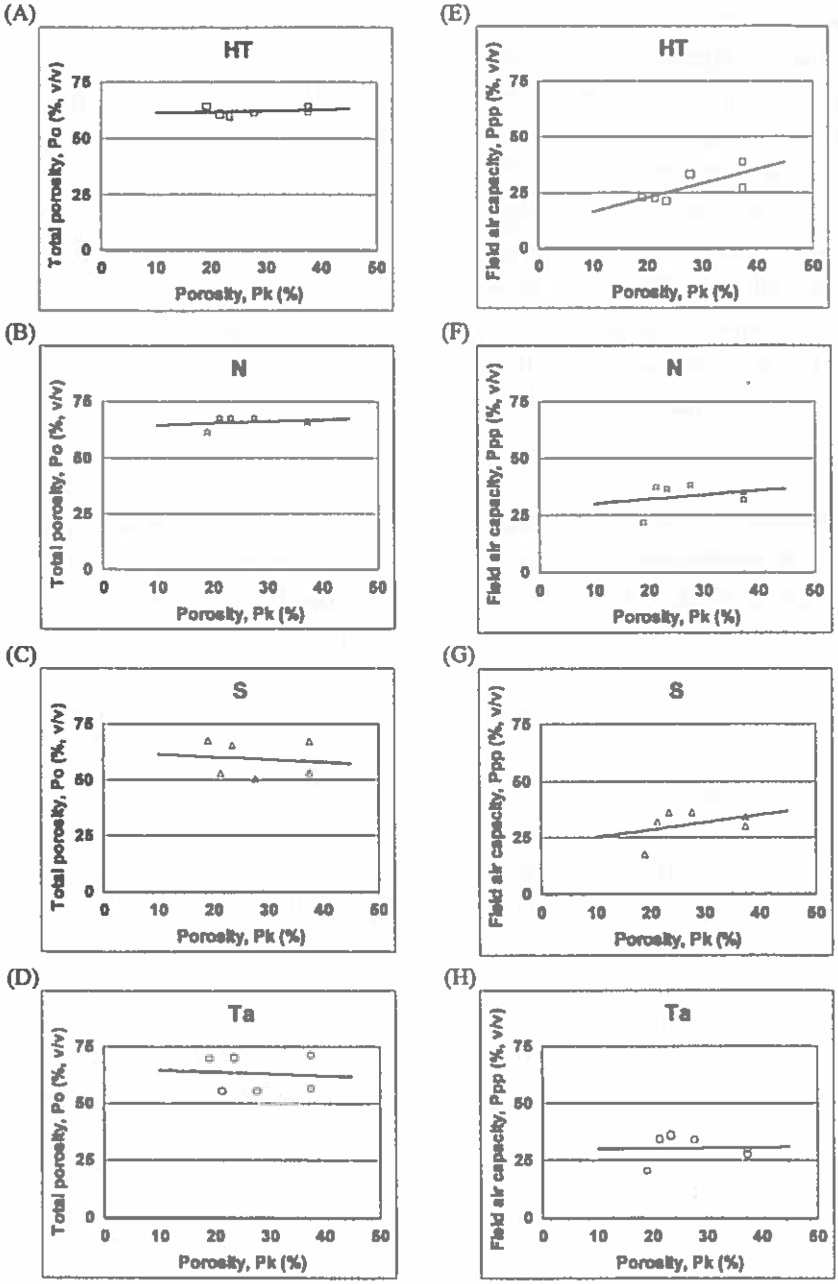

Fig. 1. (A – D) Total porosity, P_O, and (E – H) field air capacity, P_{PP}, as a function of porosity by morphometrical analysis, P_K, for each of the four soils. Symbols are explained in the text.

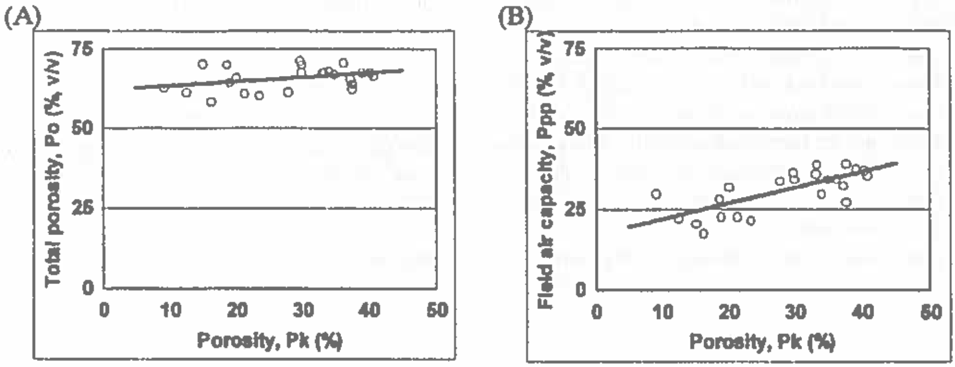

Fig. 2. (A) Total porosity, P_O, and (B) field air capacity, P_{PP}, as a function of porosity by morphometrical analysis, P_K, for all the samples.

CONCLUSIONS

1. Statistical analysis revealed significant valid relations between the porosity values obtained by morphometrical analysis, P_K, and total porosity value, P_O, or field air capacity, P_{PP}.

2. For the majority of samples, the values of porosity obtained by use of computer image analysis, P_K, were lower than those of field air capacity, P_{PP}, which is the volume of pores with diameter bigger than 20 μm. It was the effect of the available resolution of the computer that allowed for the identification of objects bigger than 200 μm.

3. To the opposite trend - the fact that porosity values derived from morphometrical analysis, P_K, are higher than those of field air capacity, P_{PP} - arises probably from unequal pore sizes in the wet (the soil water retention data) and the dry soil state (image analysis).

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