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WATER PERMEABILITY AS A FACTOR OF THE SOIL STRUCTURE

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The water management, a basic aim of which is to control the natural water resources, is closely connected with the water circulation in the biosphere. One of the most important objects in nature responsible for the water circulation in the biosphere is soil performing the role of a water distributor receiving atmospheric precipitations, possibly retaining them and partly translocating them to deeper horizons and feeding subterranean waters as well as returning a part of the water to atmosphere by means of evaporation and transpiration. Soil jointly with the area inclination determines also the water amount flowing down over its surface [4, 6, 7, 9]. There are its two properties : capacity and permeability of water, which exert a basic effect on relations between components of the water balance of soil. The water capacity determines, namely, the possibility of water retention by soil, whereas the permeability is responsible for its ability to translocate water into deeper layers [4, 5].

The aim of the present work was to determine the soil structure effect on the value of the water permeability coefficient. The recognition of this dependence will, namely, enable to execute agronomy measures aiming at changes of the aggregation of soil from the viewpoint of the content of water retention in the soil profile, mainly in the period of snowmelt in spring and intensive rainfalls in summer. It is of importance particularly in the areas, where a low permeability of arable layer makes impossible the water infiltration into soil and, jointly with the area inclination, constitutes a main cause of the soil erosion [1, 2].

INVESTIGATION METHODICS

The investigations were carried out on chernozem developed from loess (Werbkowice), distinguishing itself with a high aggregation degree and a considerable waterproofness of soil aggregates. The soil material was taken from the arable layer in the form of horizontal monoliths dried up in the laboratory for the air-dry state and passed through sieves with the mesh diameter of 0.25, 0.5, 1.0, 3.0, 5.0 and 10.0 mm. With the fractions of aggregates: <0.25, 0.25–0.5, 0.5–1, 1.0–3.0, 3.0–5.0 and 5.0–10.0 mm, separated in the way as above, cylinders with the capacity of 100 cm^3 were filled up at use of a vibrator, to ensure a uniform density. Then the aggregates were subjected to wetting-drying cycles, which resulted in a stabilization of physical properties of samples, necessary for further investigations. At the same time it is to stress that an averabe diameter of aggregates of each fraction, e.g. 2 mm for the fraction of 1.0–3.0 mm, has been assumed as an independent variable. It resulted from the fact an appropriate mechanical cultivation of soil enables getting the wanted monoaggregation of soil, which, however, can change under the effect of outer factors (precipitations, temperature); non the less it constitutes always a definite function of the initial aggregation of soil [10].

Total porosity of aggregated soil samples were determined by the Loebell's porometer, whereas the little, medium and large pores (their percentage in the total volume of sample) was calculated on the basis of water retention curves.

Investigations aiming at determination of the water permeability coefficient value were carried out at use of the apparatus for the water permeability measurement, constructed by Zawadzki and Olszta [11] at the Branch Division of the Institute for Land Reclamation and Grassland Farming in Lublin. The investigations were carried out by the method of measurement at a constant hydraulic pressure, consisting in the measurement of flow and pressure differnce between the water level in the water container and the cylinders with soil. The measurements were carried out in 20 replications for every fraction of aggregates within 12 subsequent days.

INVESTIGATION RESULTS AND THEIR DISCUSSION

Results of the investigations on the water permeability coefficient from differently aggregated soil samples in consecutive days of the measurement have proved that the size of aggregates affects the water permeability of soil (Table 1). The highest water permeability coefficients showed soil samples built of large aggregates, i.e. of 5–10 and 3–5 mm in dia, the lowest — those containing small-sized aggregates, i.e. less than 0.25 and 0.25–0.5 mm in dia. Water permeability coefficient values for aggregates of <0.25 mm in dia corresponded with the water permeability of silty sand, for those of 0.25–0.5 mm in dia — with the

Table 1

Water permeability coefficient values for aggregated soil samples

Day \ Initial fraction mm	Water permeability coefficient $k\ \bar{X}\ 10^{-2}$ cm • s^{-1}					
	< 0,25	0.25-0.5	0.5-1	1 - 3	3 - 5	5 - 10
1	0.08	0.23	1.63	3.33	16.5	29.3
	0.08	0.21	1.61	3.08	17.7	27.5
3	0.10	0.23	1.53	2.66	19.3	26.7
4	0.08	0.20	1.50	2.75	20.1	25.2
5	0.10	0.21	1.55	2.83	19.7	23.5
6	0.06	0.21	1.55	2.66	19.7	22.8
7	0.06	0.21	1.56	2.50	19.5	21.8
8	0.08	0.20	1.53	2.75	19.3	21.8
9	0.08	0.21	1.53	2.66	19.3	21.5
10	0.08	0.21	1.58	2.56	19.3	21.7
11	0.08	0.21	1.55	2.66	19.3	21.7
12	0.08	0.21	1.55	2.66	19.3	21.7

water permeability of fine-grained sand, for those of 0.5–1.0 and 1.0–3.0 mm in dia — with of medium- and coarse-grained sand, whereas for those of 3–5 and 5–10 mm in dia — with that of fine-grained gravel (Fig. 1) [3, 8, 11]. Hence the aggregates of 3–5 and 5–10 mm in dia can be assigned to strongly permeable formations, those of 0.25–0.5, 0.5–1.0 and 1.0–3.0 mm in dia belong to medium permeable and those of <0.25 mm in dia — to weakly permeable formations [3].

It follows from the data presented in Table 1 that the water permeability value for aggregates of >1 mm in dia underwent changes in the course of the experiment. The water permeability for aggregates of 1–3 and 5–10 mm in dia decreased accordingly from 3.33×10^{-2} cm • s^{-1}, to 2.66×10^{-2} cm • s^{-1} and from 29.3×10^{-2} cm • s^{-1} to 21.8×10^{-2} cm • s^{-1}, whereas the permeability of aggregates of 3–5 mm in dia increased from 16.5×10^{-2} cm • s^{-1} up to 20.1×10^{-2} cm • s^{1-} and then decreased down to 19.3×10^{2}– cm • s^{-1}. After 6–8 days of investigations a stabilization of the water permeability coefficient value was observed. Such course of the water permeability coefficient value in aggregated samples in the course of investigations can be explained by changes of situation of the finest soil particles caused by water movements in the soil sample, which would result in closing and opening of pores of different size, what led consequently in the first phase of the experiment to changes of their permeability.

The total porosity and the percentage of little, medium and large pores for different fractions of soil aggregates is put together in Table 2, whereas in Fig. 2 the relationship between the size of aggregates on

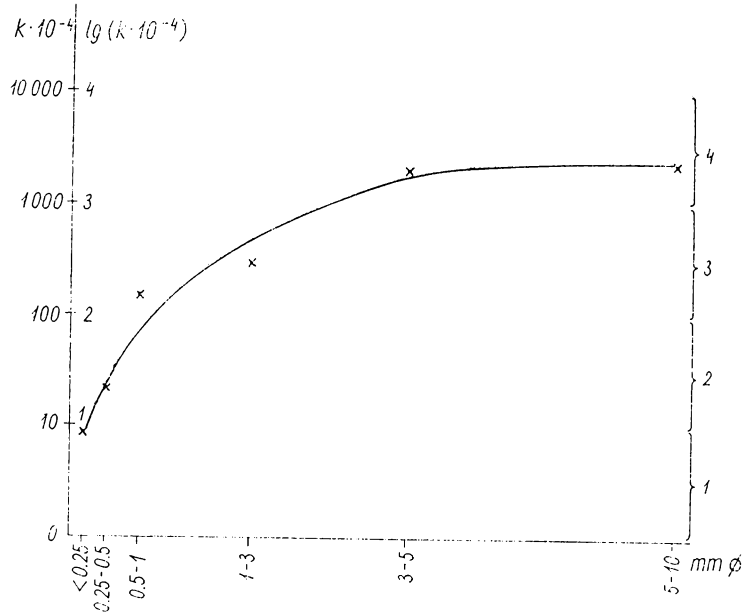

Fig. 1. **Water permeability** coefficient value for aggregates of different size and ranges of water permeability coefficient values for different formations after Hillel

1 — silty sand, 2 — fine-grained sand, 3 — medium- and coarse-grained sand, 4 — fine-grained gravel

Values of the water permeability coefficient are mean values obtained in the last four days of the measurement, when the water permeability became stabilized

Table 2

Total porosity and percentage of pores of different diameter in aggregated soil samples

Initial fraction mm	Total porosity $\%m^3m^{-3}$	Number of pores of chosen diameters - $\%m^3m^{-3}$		
		$< 0.2 \times 10^{-6}$m little	$0.2-18.5 \times 10^{-6}$m medium	$> 18.5 \times 10^{-6}$m large
< 0.25	53.5	14.2	32.1	7.2
0.25 - 0.5	62.3	11.5	28.5	22.3
0.5 - 1	65.0	10.7	17.7	36.6
1 - 3	63.0	11.3	14.0	37.7
3 - 5	67.5	9.9	16.7	40.9
5 -10	67.0	10.0	15.1	41.9

the one hand and total porosity (P_o) and the number of large pores (P_d) on the other is presented. The data put together in Table 2 prove a low influence of the size of aggregates on the total porosity and the number of little pores contained in the soil samples examined. However, they

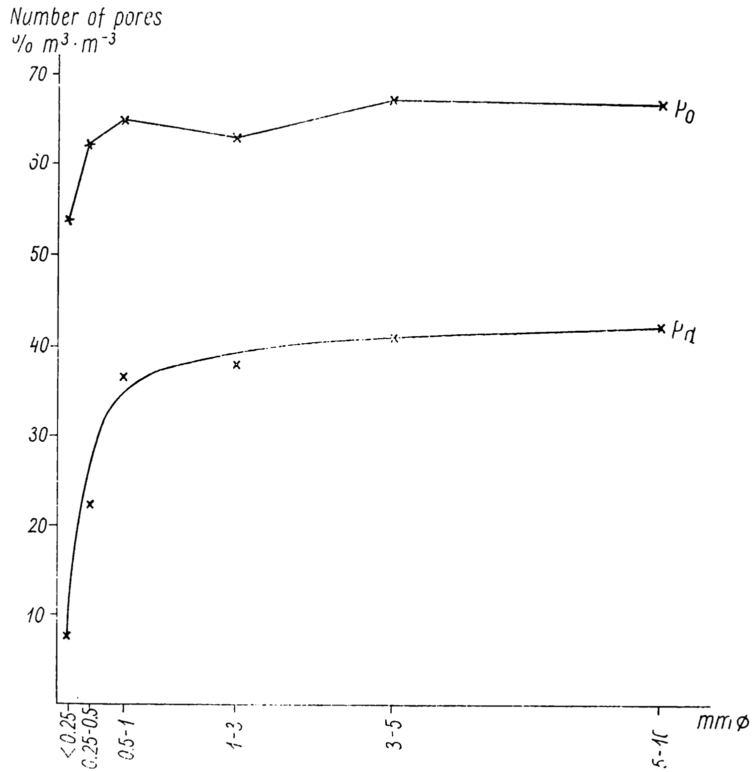

Fig. 2. Relationship between the size of aggregates on the one hand and the total porosity (P_0) and the number of large pores (P_d) on the other

lead to the conclusion that along with an increase of the size of aggregates decreases the number of medium pores (from 32.1% m^3m^{-3} for aggregates of <0.25 mm in dia down to 15.1% m^3m^{-3} for aggregates of 3–10 mm in dia), at a simultaneous increase of the number of large pores. The number of large pores amounted for aggregates of <0.25 mm in dia to 7.2% m^3m^{-3} and for aggregates of 5–10 mm in dia — to 41.9% m^3m^{-3}. On the basis of the situation of pores (Fig. 2) and of the respective calculations it has been proved that the relationship between the number of large pores and the size of aggregates is of the character of a function, the general shape of which would be :

$$P_d = a \sqrt[n]{\phi}$$

where:
P_d — the number of large pores (% m^3m^{-3}),
ϕ — diameter of aggregates (mm),
a, n — coefficients depending on the soil kind.

In case of the soil under study the above function would assume the shape of

$$P_d = 25.64 \sqrt[3]{\emptyset}$$

While comparing the character of the dependence on the water permeability coefficient value on the size of aggregates (Fig. 1) as well as of the number of large pores on the size of the growth of the water can be concluded that a direct cause of the growth of the water permeability coefficient value along with an increase of the size of aggregates would be the growth of the number of large pores caused by the increased number of aggreates contained in soil samples.

The relationship between the water permeability coefficient value and the number of large pores in soil samples containing aggregates of different size, is presented in Fig. 3. The course of this relationship

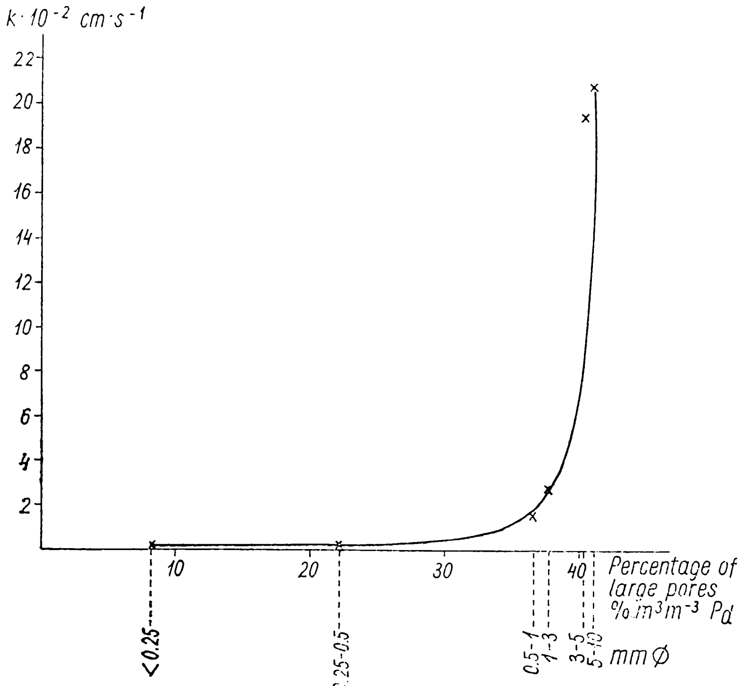

Fig. 3. Relationship between the water permeability coefficient value and the number of large pores in soil samples of different size of aggregates

illustrates the effect of the number of large pores in the soil on the water permeability coefficient value, which can be described on the basis of the situation of points and respective calculations by the function, the general shape of which would be :

$$k = a\ (P_d)^n$$

where :

k — water permeability coefficient ($cm \cdot s^{-1}$),

P_d — number of large pores ($\% \ m^3m^{-3}$),

a, n — parameters depending on the soil kind.

In case of the soil under study the above function would assume the shape of

$$k = 15 \cdot 10^{-7}\ (P_d)^3$$

Moreover, it can be stated basing on Fig. 3 that there is a boundary number of large pores determined by the size of aggregates, the excess of which would lead to a rapid growth of the water permeability of soil. In case of the soil under study it would be the value lying within the interval of 37.7—40.9% m^3m^{-3} of the number of large pores. This boundary value of the number of large pores in a valuable practical index enabling to state that the attainment ow growth of the water permeability of soil would be possible only in case of such changes of the size of aggregates, which would result in a growth of the number of large pores over the above value. It means that for chernozem such mechanical cultivation should be applied to ensure the possibility of absorption and translocation of water from its surface in great amounts, in result of which in the arable layer aggregates of the size of 3–10 mm in dia could be formed.

RECAPITULATION

On the basis of the respective investigations and their results it has been found that the size of aggregates, of which the arable layer is built, determines, the value of the water permeability coefficient in such a way that along with the growth of the size of aggregates an increase of the water permeability coefficient value would take place. The above relationship is conditioned directly by the effect of the size of aggregates on the number of large pores (of the diameter exceeding 18.5×10^{-6} m), which is the function of the shape of $P_d = a \sqrt[n]{\Phi}$, whereas the relationship between the water permeability coefficient value and the number of large pores assumes the shape of the function of $k = a\ (P_d)^n$. In case of the soil under study, i.e. of chernozem developed from loess, the relationship assume the shape of $P_d = 25.6 \sqrt[3]{\Phi}$ and $k = 15.10^{-7}\ (P_d)^3$.

Moreover, it has been found that there is a boundary number of large pores conditioned by the size of aggregates, the excess of which would lead to a rapid growth of the water permeability coefficient value. Its knowledge is a practical index of the way and direction of measures of mechanical cultivation of soil to be carried out, aiming at an increase of the water permeability of soil, and consequently at an increase of the amount of water retained in the soil profile.

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PRZEPUSZCZALNOŚĆ WODNA JAKO FUNKCJA STRUKTURY GLEBY

Zakład Agrofizyki PAN w Lublinie

Streszczenie

Przedstawiono wyniki badań wpływu wielkości agregatów glebowych na współczynnik przepuszczalności wodnej w strefie nasyconej. Stwierdzono, że wielkość agregatów tworzących warstwę orną gleby determinuje przepuszczalność wodną w taki sposób, że wraz ze wzrostem wielkości agregatów wzrasta współczynnik przepuszczalności, a zależność ta warunkowana jest wpływem wielkości agregatów na ilość porów dużych. Związek między wielkością współczynnika przepuszczalności wodnej a ilością porów dużych ma postać funkcji $k=a\ (P_{d})^{n}$. Ponadto stwierdzono, że istnieje graniczna ilość porów dużych warunkowana wielkością agregatów, przekroczenie której powoduje gwałtowny wzrost przepuszczalności wodnej. W przypadku agregatów czarnoziemu wytworzonego z lessu jest to wartość znajdująca się w przedziale 37,7–40,9% (m^3m^{-3}) ilości porów dużych w ogólnej objętości próbki.

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