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POROSITY LIMITS OF POLISH SOILS

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A b s t r a c t. Fifty five soils from various regions of Poland, representing the main soil types, kinds and genera were examined to establish boundary values of their porosities: maximum and minimum porosity or maximum loosening and maximum compactness in an arable layer, according to procedures elaborated earlier [2]. Between the porosity limit values thus determined fall all states of a natural or field porosity. It was documented and explained that knowing the value of field porosity and the boundary values of porosity for a given soil, one can determine, in a precise and objective way, the soil porosity indices and grades. As it is generally known, field porosity of, for example 40 %, can prove to be a very low value for one soil texture (reflecting its very high compaction) and yet be a relatively high value (very low compaction) for another soil. Therefore, the grades and indices of porosity allow us to determine the porosity changes of a given soil in an accurate and relatively detailed way. These procedures are suitable especially for evaluation of porosity between soils differing in texture. Table 1 presents an example of the determination of the degree and indices of porosity for various soil types, kinds, and genera when the porosity of these soils is 40 %. It was also noted that each soil texture has a specific, characteristic value and a specific interval of limiting values of porosities.

INTRODUCTION

Porosity proves to be one of the most vital and characteristic properties of soil structure, particularly of the cohesive and granular type of structure. Soil structures in the broad sense include retention and soil water capacity, water-air ratios, compaction, etc., Consequently it affects conditions for the development of plant root systems.

It is important to analyse porosity, particularly to characterize the state of the cohesive structure in the soil arable layer where porosity may undergo relatively rapid changes within a broad range of limits.

In order to determine porosity, metal cylinders (rings) with a cutting edge are most frequently used. The cylinders cut out samples of undisturbed structure, usually with a 100 cm^3 volume. Samples collected in this way can be used to determine the actual and total porosities using suitable pneumatic pycnometers or making use of the gravimetric method. The results are most frequently expressed in percentages or as a porosity coefficient.

However, porosity determinations cannot be interpreted in an accurate or comparable way since the total porosity at the level of e.g., 50 % can prove to be a relatively high value for one soil texture and yet be a relatively low value for another soil. This has been documented in previous papers [1,2]. However, if the porosity limit values are known, namely the minimum and maximum porosity of a given soil, a porosity of for example 50 %, can be adequately placed within the interval of limiting values. In order to indicate the position of porosity in an accurate and relatively detailed way, intervals between the limiting values of porosity were divided into classes, degrees and coefficients of porosity. These proved to be suitable ways of comparing soils, which are genetically or physically different. The way of determining the minimum and maximum porosities as well the categorizing of porosities into classes, degrees and coefficients are presented in a separate publication on the method [2]. In this paper we focus on the determination of porosity limits for the most important soil textures in Poland. The essential results of the investigations can be generalized in the following way: (i) the size of minimum and maximum porosities as well as the interval between those limiting values depend mainly on soil texture, above all on the percentages of clay, silt and sand as well as on the ratios between those fractions; (ii) each soil texture has a specific, characteristic value and specific interval of limiting values; (iii) data included in this paper can be used to approximate porosity class, degree or coefficient for the soils considered; however, for more detailed purposes, limiting values should be determined in the manner described in an earlier publication on the method [2].

MATERIALS AND METHODS

The investigations included 55 mineral soils representing the most important arable soil textures in Poland: brown soils, grey-brown podzolic soils, black soils, muck soils (up to 5 % organic substance), rendzinas and chernozems. The parent materials were boulder loams of Riss and Würm glaciations, loesses, Carpathian flysch, alluvial soils, fluvio-glacial deposits, Cretaceous and Jurassic limestones. The texture of soil was extremely varied-from sands to clays. The basic physical properties of the soils analysed, location of the investigation sites etc. are given in a preceding paper. Maximum and minimum porosities were determined using the methods presented in an earlier publication [2], where assumptions, rationale and concept of the investigations, porosity classification, interpretation of results, etc., can also be found. This paper focuses only on the explanations of two basic features, namely the minimum and maximum porosities. The minimum porosity, or the maximum compaction was obtained by wetting air-dry soil with an amount of water (*Wsz*) for which maximum compaction was achieved while preparing soil. The preparation gets rid of the air which limits the compacting action of water. As a result of this tempering effect, a very strong, reproducible, homogeneous and relatively stable compaction is obtained which is characteristic of each soil texture. This is a result of high potential energy at the solid-liquid interface of the soil. These types of phenomena also exist in natural conditions, but they occur in a much slower and more complicated way than in the laboratory. In the field, the natural compaction of soils is restricted and modified by the presence of the gaseous phase. However, at the end of the vegetative period, after the soil has been repeatedly wetted and dried, its compaction usually approximates the maximum limit determined in the laboratory. Thus the maximum state of soil compaction achieved by the use of the natural factor-water, can be regarded as the natural state which occurs in the soils due to the compacting effect of soil water which comes from precipitation. The other limiting value-maximum loosening or maximum porosity is achieved by a method [2] which is the result of complete (100 %) aggregation of the soil in 2-4 mm aggregates. This limit does not occur under the natural conditions. It is however, a value characteristic of a given soil texture, determined in a simple and reproducible way under laboratory conditions.

RESULTS AND CONCLUSIONS

The most significant findings are presented in Table 1 where 55 soils were divided into 9 groups according to soil parent materials (*A-J*). General characteristics of the groups can be found in a previous publication [3] in Table 1. Within each group, the soils are ranked according to increasing clay percentage (Table 1). The table also shows percentages of silt and organic matter. The next two columns include the maximum (Pc max) and minimum (Pc min) porosities of soils. These values were estimated using a method described in an earlier publication [2]. The next column -7 presents the difference of porosities: Pc max - Pc min. Between porosity limits, one can find various natural porosities which vary in time and which exist under field conditions. Knowing the value of field porosity and the above-mentioned boundary states, one can determine the index and grade of a given soil. As was previously mentioned, indices and grades, thus determined, make it possible to compare porosities of soils of different physical properties in a precise, verifiable and objective way. Soil porosity indices and grades as well as the way to determine them are presented in Fig. 1 [1,3], whereas examples of indices and grades determined for a 40 % porosity are shown in columns 8 and 9 of Table 1. The remaining two columns of Table 1 are soil moisture states (% w/w)) at which the soils achieved their maximum compaction or maximum loosening. Another examples of how to determine porosity indices and grades as well as how to use the limits in the analysis of porosities of different soils are presented in Fig. 2.

The findings presented in Table 1 can be summed up in the following conclusions.

1. The minimum porosity that occurs in soils compacted under the influence of a standard quantity of water while kneading the soil mass, can achieve some very low values (20.0 % soil No. 1) and some relatively high (41.7 % soil No. 9). This type of soil compaction depends mainly on the percentage of clay, silt and sand. Moreover, it is also dependent on soil development and physical properties, parent materials and organic matter content. Under the natural conditions, soil porosity can approach the maximum compaction but not exceed it. The lowest porosity was found in soils formed from glacial deposits (mostly 24-30 %), slightly higher in alluvial soils (25-33 %) and rendzinas (mostly 30-35 %). Significantly higher porosities were found in soils formed from loesses and loess-like loams (30-44 %, Nos 47 and 48). The highest value was observed in the soil formed from clays (41.7 % soil No. 9).

2. Maximum porosity depends on the factors mentioned above (item 1); however, the state of porosity is determined by these

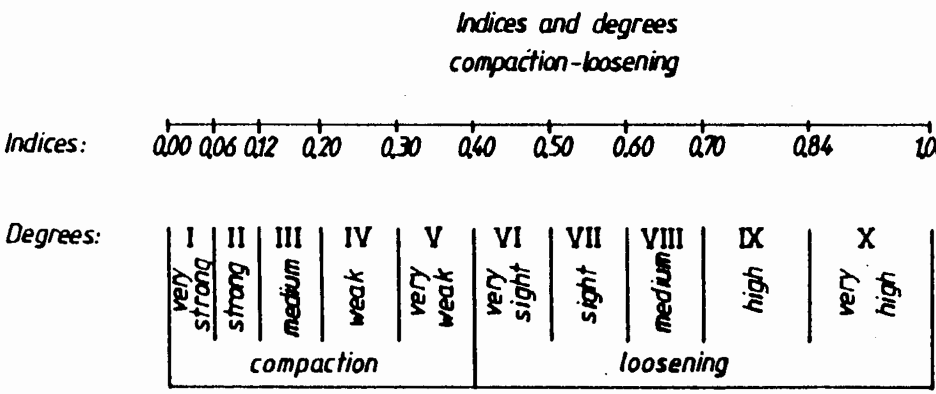

Fig. 1. Porosity degrees and indices of soil compaction-loosening.

Table 1. Porosity limits of soils

	No. of soil	Fraction (%)		Organic matter	Porosity (Pc) (%)			Field porosity (Pcx) = 40 % (for examples)		Compacting moisture	Loosening moisture
		<0.002 mm	0.05-0.002 mm	(%)	Pc min	Pc max	Pc	index	degree	(%)	(%)
	1	2	3	4	5	6	7	8	9	10	11
A	27	0	1	2.95	30.90	66.50	35.60	0.26	IV	13.50	16.63
	18	2	3	0.86	36.40	64.80	28.40	0.13	III	9.50	15.34
	19	2	7.5	2.86	29.80	69.00	39.20	0.26	IV	19.60	17.08
	17	3	8	1.38	29.40	62.00	32.60	0.33	V	16.60	12.76
	20	3	13	2.58	36.80	70.30	33.50	0.10	II	20.30	20.38
B	11	3	35	0.89	30.90	61.00	30.10	0.30	IV	15.50	14.03
	54	5	19	1.91	23.70	63.90	40.20	0.41	VI	13.00	12.95
	12	5	23	0.84	24.50	61.30	36.80	0.42	VI	14.40	14.34
	3	6	28	2.22	23.80	68.00	44.20	0.37	V	14.50	14.54
	15	9	27	2.10	25.00	67.00	42.00	0.36	V	22.00	16.21
	1	11	31	1.98	20.00	68.00	48.00	0.42	VI	18.00	16.90
	4	13	28	2.29	23.00	65.00	42.00	0.40	V	18.00	15.49
	2	14	33	2.17	28.70	70.20	41.50	0.27	IV	20.60	16.48
	55	16	20	3.86	25.40	70.10	44.70	0.33	V	17.00	16.34
C	26	1	17	1.40	29.10	63.40	34.30	0.32	V	14.00	12.61
	42	3	20	0.95	20.30	64.00	43.70	0.45	VI	16.50	12.91
	24	3	24	1.05	26.30	63.70	37.40	0.37	V	14.30	13.71
	53	4	14	1.64	26.60	64.10	37.50	0.36	V	10.50	11.80
	44	4	18	1.47	24.30	67.10	42.80	0.37	V	14.50	14.57
	25	4	20	1.34	27.60	66.30	38.70	0.32	V	15.00	14.72
	23	10	21	3.10	32.40	72.80	40.40	0.19	III	19.00	16.27
	45	12	21	1.66	27.50	67.40	39.90	0.31	V	13.00	12.67
D	51	16	57	3.65	38.10	72.20	34.10	0.06	I	24.00	21.00
E	47	12	69	1.86	33.80	70.40	36.60	0.17	III	20.00	20.13
	48	24	56	1.65	36.30	72.50	36.20	0.10	II	19.00	21.00
F	29	4	72.5	2.02	39.70	69.60	29.90	0.01	I	19.50	21.14
	37	4	78	2.90	39.80	71.10	31.30	0.01	I	19.50	23.96
	36	4	79	2.62	37.20	70.70	33.50	0.08	II	24.00	22.35
	30	7	70.5	2.81	34.60	69.60	35.00	0.15	III	20.00	19.64
	22	8	43	2.37	33.60	70.20	36.60	0.17	III	17.50	18.49
	40	8	67	2.32	32.50	67.00	34.50	0.22	IV	16.00	16.84
	21	10	46	2.19	32.00	66.70	34.70	0.23	IV	17.00	16.43
	14	10	53	2.58	31.00	67.00	36.00	0.25	IV	22.00	17.42
	35	11	70	1.26	39.00	70.60	31.60	0.03	I	21.50	21.39
	46	13	64	1.60	35.90	71.80	35.90	0.11	II	21.00	15.90
	31	14	67	4.78	37.30	70.10	32.80	0.08	II	23.00	22.12
	39	14	75	1.43	36.50	67.30	30.80	0.11	II	19.00	19.81
	52	16	64	1.86	32.80	70.10	37.30	0.19	III	18.50	15.52
	13	26	53	3.02	29.20	75.00	45.80	0.24	IV	21.00	23.07
G	41	4	45	3.08	33.30	67.90	34.60	0.19	III	15.50	18.78
	16	6	30	2.76	31.00	69.00	38.00	0.24	IV	24.60	20.26
	6	8	28	1.46	25.00	65.00	40.00	0.38	V	18.60	16.70
	43	10	37	2.33	22.30	72.00	49.70	0.36	V	16.50	16.41
	5	16	51	2.40	31.10	71.20	40.10	0.22	IV	20.60	21.29
	7	17	51	2.59	33.00	74.60	41.60	0.17	III	25.80	20.15
	8	21	38	2.02	25.00	71.00	46.00	0.33	V	25.00	18.10

1		2	3	4	5	6	7	8	9	10	11
H	28	4	16.5	2.03	25.00	66.00	41.00	0.37	V	17.50	15.24
	32	8	15	1.12	32.50	63.50	31.00	0.24	IV	15.00	16.08
	49	10	25	2.75	32.10	75.00	42.90	0.18	III	19.00	17.87
	33	12	21	2.46	31.60	73.60	42.00	0.20	III	20.50	21.48
	38	13	43	2.33	29.00	74.40	45.40	0.24	IV	19.50	19.63
	34	25	18	3.10	34.20	79.50	45.30	0.11	II	24.00	19.86
	50	26	24	3.17	35.70	76.80	41.10	0.10	II	24.50	20.08
I	9	33	38	4.01	41.70	78.60	36.90	0.04	I	34.00	24.85
	10	40	29	2.81	37.20	79.90	42.70	0.07	II	28.00	27.36

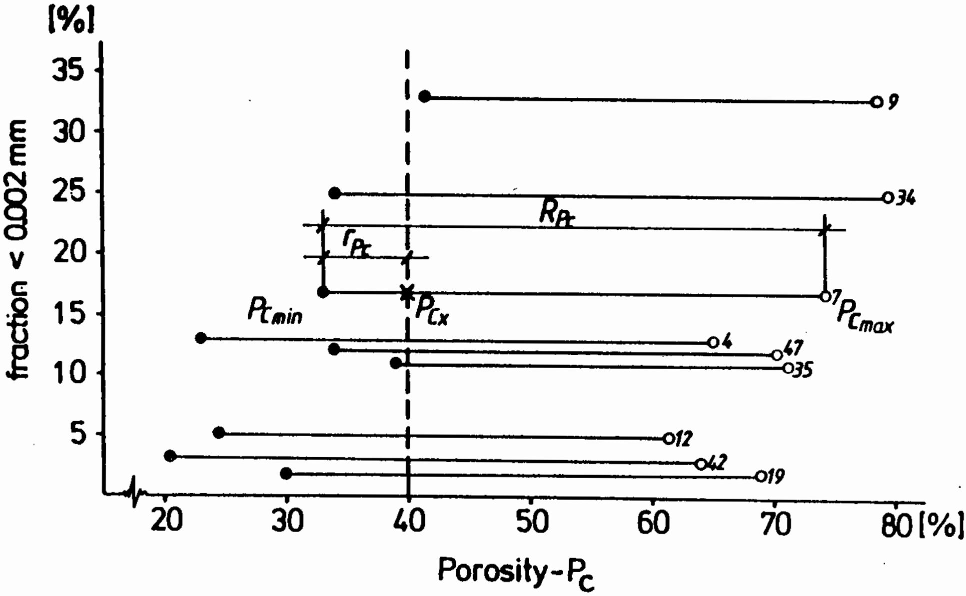

Fig. 2. An example of porosity limits (Pc max - Pc min) and natural porosity (Pcx) to determine indices and degrees of soil compaction and loosening.

$$Z_x = \frac{r_{P_c} \cdot 1{,}0}{R_{P_c}} = \frac{(P_{c_x} - P_{c_{min}}) \cdot 1{,}0}{P_{c_{max}} - P_{c_{min}}}$$

where: R_{P_c} - difference between maximal and minimal porosity ($P_{c_{max}}$ - $P_{c_{min}}$) for a given soil; r_{P_c} - difference between any natural soil porosity state (P_{c_x}) and minimal porosity ($P_{c_{min}}$) for a given soil; 1,0 - index of maximum loosening.

factors in a slightly different way than for minimum porosity. The smallest values were found in glacial soils (61.0-72.8 %), generally significantly higher ones in loess soils (66.7-75.0 %, most frequently around 70 %), markedly higher in rendzinas, particulary very cohesive rendzinas (mostly over 70 %, maximum 79.5 %).

The highest porosities were found in clays (soil No. 10-79.9 %).

3. Minimum and maximum porosities can be obtained for soils with identical or very similar soil moisture contents (soil Nos 20, 54, 3, 44, 47, 35, 43, 38). For minimum porosity, the gaseous phase was significantly reduced (through tempering the soil for maximum porosity) however, the gas phase was increased by rotating moist soil in a sieve set.

4. Intervals between maximum and minimum porosities differ greatly for different soils. The lowest value is 28.4 % (No.18),the highest one is 49.7 % (No. 43). Soils formed from loesses are characterized by relatively small intervals whereas cohesive alluvial soils and rendzinas by relatively high intervals (over 40 %).

5. If we assume that under natural conditions, the porosity of those soils which were investigated would be e.g., 40 %, we could determine appropriate porosity indices and grades making use of the porosity limits and of the proposed classification (Fig. 1). Thus, the lowest porosity index would be found for soil No.9 (-0.04) and the highest for soil No.42 (0.45). In the case of soil No. 9, a 40 % porosity would prove to be an unobtainable value since the maximum compaction is 41.7 %. The range of porosity indices, ranging from 0.0 to 0.45 is very large and the differentiation is also large. A better comparison of soils can be obtained by use of porosity grades. Some soils would be classified as follows: Class I (very strongly compacted soils, Nos 51, 29, 37, 35, 9); Class II - strongly compacted soils, Nos 20, 48, 36, 46, 31, 39, 34, 50, 10; Class III - medium compacted soils, Nos 18, 23, 47, 30, 22, 52, 41, 7, 49, 33; Class IV - slightly compacted soils, Nos 27, 19, 11, 2, 40, 21, 14, 13, 16, 5, 32, 38; Class V - very slightly compacted soils, Nos 17, 3, 15, 4, 55, 26, 53, 44, 25, 45, 6, 43, 8, 28 and Class VI - very slightly loosened soils, Nos 54, 12, 1, 42. Thus, for some loess soils, a 40 % porosity proves to be a very strongly compacted state (Nos 29, 37, 35); whereas for some glacial soils, it is a very slightly loosened state (Nos 54, 12, 1, 42). Therefore, the natural (field) porosity itself proves to be insufficient to obtain a comparable and precise estimation of the soil's physical state, especially its structure. However, its diagnostic value increases significantly when used with porosity limits.

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GRANICZNE POROWATOŚCI GLEB POLSKI

Dla 55 gleb z różnych regionów Polski, reprezentujących najważniejsze typy, rodzaje i gatunki gleb, określono stany granicznej porowatości, a więc stany porowatości maksymalnej i minimalnej, czy maksymalnego spulchnienia i maksymalnego zagęszczenia warstwy ornej gleb uprawnych. Oznaczenia przeprowadzono wg metodyki opracowanej i opublikowanej przez autorów [2]. Pomiędzy tak oznaczonymi wartościami granicznymi porowatości, mieszczą się wszystkie stany porowatości naturalnej, czy polowej. W pracy wykazano i uzasadniono, że oznaczenia granicznych stanów porowatości określonej gleby pozwalają na obiektywne i względnie ścisłe określenie stopnia i wskaźnika porowatości, gdy znamy jej porowatość polową. Jak wiadomo, porowatość polowa na poziomie np. 40 % może być dla niektórych gleb wartością bardzo niską (bardzo silne zagęszczenie), dla innych może być względnie wysoką (bardzo słabe zagęszczenie). Stopnie i wskaźniki porowatości pozwalają na relatywną ocenę zmian porowatości określonej gleby, a przede wszystkim różnych gleb o zróżnicowanej i zmiennej w czasie porowatości. Podano przykłady określania stopni i wskaźników dla różnych typów, rodzajów i gatunków gleb, gdy ich porowatość polowa wynosiłaby 40 %. Ponadto wykazano, że każda gleba ma swoisty stan liczb granicznych i związany z tym przedział porowatości.