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SELECTED PHYSICAL AND CHEMICAL PROPERTIES AND THE STRUCTURE CONDITION OF PHAEOZEMS FORMED FROM DIFFERENT PARENT ROCKS
Part II. The state of arable phaeozems horizons' structure

Summary

The paper analyses characteristic structure-forming properties such as: the dynamic and static water resistance of soil aggregates, the secondary aggregation following the dynamic and static water action, capillary water capacity, volume changes caused by swelling and shrinkage of soil aggregates and their mechanical strength for six topsoil horizons of phaeozems. Experiments were carried out in carefully controlled moisture and compaction conditions of modelled soil aggregates of $V=1$ cm^3. The aggregates were characterised by a considerable variability of texture, especially of the colloid fraction content (from 10 to 54%) as well as a significant variation in the content of organic matter (from 27.6 to 41.0 $g \cdot kg^{-1}$). Basically, the above two factors determined the structure-forming potentials of the examined soils. The secondary aggregation, following the dynamic and static water action, measured by the amount of secondary aggregates > 0, 25 mm, ranged from 26 to 89%. High retention potentials of the examined aggregates led to considerable volume alterations in the course of drying and moistening processes: shrinkage reached the value of 54%, while swelling attained the value of even 80% of the initial aggregate volume. Consequently, loosening or compaction of the aggregate solid state occurred, leading to their varying suscaptability to the action of external factors, including their resistance to the action of water and mechanical strains.

WYBRANE WŁAŚCIWOŚCI FIZYCZNE I CHEMICZNE ORAZ STAN STRUKTURY CZARNYCH ZIEM WYTWORZONYCH Z RÓŻNYCH SKAŁ MACIERZYSTYCH
Część II. Stan struktury poziomów uprawnych czarnych ziem

Streszczenie

W pracy analizowano charakterystyczne cechy strukturotwórcze, takie jak: dynamiczną i statyczną wodoodporność agregatów glebowych, stan agregacji wtórnej po dynamicznym i statycznym działaniu wody, kapilarną pojemność wodną, zmiany objętościowe wywołane pęcznieniem i skurczem agregatów glebowych oraz ich mechaniczną wytrzymałość dla sześciu poziomów orno-próchnicznych czarnych ziem. Badania prowadzono w ściśle kontrolowanych warunkach wilgotności i zagęszczenia modelowanych agregatów glebowych o $V=1cm^3$. Agregaty charakteryzowały się dużą zmiennością składu granulometrycznego, szczególnie zawartości frakcji koloidalnej (od 10 do 54%), a także istotnym zróżnicowaniem zawartości materii organicznej (od 27,6 do 41,0 $g \cdot kg^{-1}$). Te dwa czynniki w zasadniczy sposób determinowały zdolności strukturotwórcze badanych gleb. Agregacja wtórna po dynamicznym i statycznym działaniu wody, mierzona ilością agregatów wtórnych > 0,25 mm, wahała się w przedziale 26-89%. Wysokie zdolności retencyjne agregatów prowadziły w procesach przesuszania i nawilżania do dużych zmian objętościowych; skurczliwość osiągała wartość 54%, a pęcznienie nawet 80% pierwotnych objętości agregatów. W konsekwencji następowało rozluźnianie lub zagęszczanie fazy stałej w agregacie, a to powodowało ich zróżnicowaną podatność na działanie czynników zewnętrznych, w tym odporności na działanie wody i naprężeń mechanicznych.

Introduction

The structure, as one of the major characteristics determining soil physical properties, is an exceptionally important issue for the appropriate description and interpretation of changes which occur in the soil profile, especially in the arable horizon [2, 3, 12]. A considerable structural variability of the topsoil layers combined with diverse physiographic conditions exerts a substantial influence on the applied agrotechnical treatments in the conditions of optimal moisture and the compaction of the arable horizon [5, 10]. The physical properties of this surface horizon, including the parameters which determine the condition of its structure, are influenced, first and foremost, by the climatic, site and agrotechnical factors. It is widely believed that properties of the topsoil are strongly affected by: texture, content of organic matter and calcium carbonate as well as by the structure-forming crop plants. It is also known that, in specific climatic and physiographic conditions, soils subjected to the typical, traditional tillage system exhibit a constant, stable humus horizon [4, 14]. In Polish conditions, soils which are characterised by higher organic matter content include phaeozems which, together with humic rendzinas, alluvial soils and chernozems, are considered soils with the most favourable structure of arable horizon, in particular – with a very good aggregate structure [8].

Research object and methodology

Investigations were carried out on soil aggregates of 1 cm^3 volume which were cut out from the central zone (10-15 cm) of topsoil horizons of six selected phaeozems. Their location and origins as well as major physical and chemical properties of the soil material of these horizons were presented in Part l of this study.

Soil aggregates of the clearly defined shape (cylinder: h = 10.0 mm, d = 11.28 mm, V = 1 cm^3) were collected during the end of the vegetative season (end of August), i.e. at the time when the arable horizon attains its highest natural compaction. The collected aggregates were divided into two parts in the laboratory: the first group comprised aggregates which were collected at natural moisture, the second – aggregates brought to their air dry state.

Investigations of soil structures were conducted on the basis of the original methodological solutions published in the years 1983-1993 [5, 7, 9] in which the authors presented the concept, principles and detailed analytical procedures. In this study, only some, albeit most important, elements of that comprehensive research program were utilised. The structural condition and variability of the arable horizon of the examined soils was assessed by the determination of the following physico-mechanical parameters of soil aggregates:

- Dynamic water resistance (DW) of soil aggregates using a dynamic water resistance analyser; the determination consists in the measurement of the energy needed to break up a soil aggregate of V = 1 cm^3 volume by the impact of water drops of 0.05 g weight falling from the height of 1 m at 1 second long intervals (kinetic energy of one drop - $E=4.905 \cdot 10^{-4}$ J) or, alternatively, expressed by means of the number of drops needed to break up the aggregate,
- Static water resistance (SW) of soil aggregates – determined in a plastic container with nylon threads spread every 0.6 cm on which aggregates are placed, and next the container is filled with water. The determination of this trait consists in the assessment of the breakup time ("soaking time") of the aggregates submerged in the water,
- The secondary aggregation following the dynamic and static water action – determined using the sieve method in the wet state on a set of sieves with mesh diameters: 7, 5, 3, 1, 0.5 and 0.25 mm. The sieves were submerged in the water where, as a result of horizontal and vertical movements, aggregates were segregated into fractions,
- The speed of water transfer within aggregates and their minimum and maximum capillary water capacity; determined on a filtration set placed on the Petri dish and flooded up with water to the level of the filter paper,
- The compression strength of aggregates – determined in the LRuTs type test apparatus.

The evaluation of water resistance and secondary aggregation was carried out on the basis of the 10-degree scale proposed by Rząsa and Owczarzak [9] presented in Table 1.

Results and discussion

Table 2 presents a number of the most important physical and chemical properties selected for investigations of six phaeozems and some parameters characterising the resistance of the aggregate structure. In this particular table, soils were listed according to the content of their coloid fraction <0.002 mm. The amount of this fraction was contained within a very wide interval of 10 to 54% accompanied by a considerable variation in the organic matter content ranging from 26.6 to 41 $g \cdot kg^{-1}$. The water content at the time of aggregate collection was contained in the interval ranging from 0.087 to 0.265 $m^3 \cdot m^{-3}$, whereas after leading to the air dry state – from 0.025 to 0.098 $m^3 \cdot m^{-3}$. Aggregate compaction for the discussed two moisture states also varied widely; aggregate bulk density in natural moisture content state was contained in the interval from 1.67 – 1.91 $g \cdot cm^{-3}$, which corresponded to the porosity ranging from 0.340 – 0.222 $m^3 \cdot m^{-3}$, whereas in the air dry state, the above parameters were, respectively: 1.23 – 1.65 $g \cdot cm^{-3}$, which corresponded to the porosity ranging from 0.500 – 0.346 $m^3 \cdot m^{-3}$.

The determined water resistance of soil aggregates also varied greatly. In the case of the dynamic water action, their water resistance fluctuated in a very wide interval, namely 37 to 11 500 drops were required to destroy a soil aggregate completely. Generally speaking, dry aggregates were clearly less resistant (37 to 533 drops) in comparison with wet aggregates (56 – 11 452 drops). Similarly wide differences in the obtained results referred to the static water resistance measured by the time needed for the aggregates to disintegrate; here the differences ranged from 140 seconds to 86 400 seconds. And also in this case, dry aggregates showed a considerably lower water resistance than wet aggregates which failed to break down even within the period of 24 hours (86 400 seconds).

Table 1. Classification of water-resistance of soil aggregates and secondary aggregation after dynamic (DW) and static (SW) water action

Degree of water resistance and degree of secondary aggregation	Name of water-resistance and degree of secondary aggregation	Dynamic water-resistance		Static water-resistance (s, min or h)	Index of secondary aggregation (%)
		number of standard drops	kinetic energy (10^{-2} J)		
1	extremely low	< 40	< 2	< 40"	< 5
2	very low	40-100	2-5	40"-1'30"	5-10
3	medium low	101-200	6-10	1'31"-3'	11-20
4	Low	201-500	11-25	3'1"-8'	21-35
5	Medium	501-1 000	26-50	8'1"-15'	36-50
6	medium high	1 001-2 000	51-100	15'1"-30'	51-65
7	High	2 001-5 000	101-250	30'1"-1 h 30'	66-80
8	very high	5 001-10 000	251-500	1 h 30'1" -6 h	81-90
9	extremely high	10 001-20 000	501-1 000	6 h 1'-24 h	91-99
10	Full	> 20 000	> 1 000	> 24 h	100

Table 2. Basic physico-chemical properties, dynamic (DW) and static (SW) water-resistance, time of capillary rise (T_{kmin}) and compressive strength (Rc) of soil natural aggregates

No. of profile	Fraction < 0,002 mm (%)	Organic matter ($g \cdot kg^{-1}$)	State of moisture ($m^3 \cdot m^{-3}$) a – air dry b - wet	Bulk density ($Mg \cdot m^{-3}$)	Porosity ($m^3 \cdot m^{-3}$)	DW number of drops	SW time of desintegration (s)	T_{kmin} (s) */	Rc (MPa)
6	10	34.0	a 0.026	1.67	0.340	37	28800	68	0.82
			b 0.087	1.46	0.416	56	28800		-
2	14	31.8	a 0.030	1.70	0.320	92	3760	285	1.49
			b 0.106	1.64	0.336	355	28800		-
1	15	27.6	a 0.028	1.76	0.304	238	2700	422	2.25
			b 0.112	1.65	0.346	483	28800		-
5	24	32.8	a 0.039	1.91	0.222	42	140	79	1.24
			b 0.142	1.29	0.480	71	520		-
3	51	41.0	a 0.098	1.90	0.228	667	28800	1180	5.70
			b 0.265	1.23	0.500	11452	28800		-
4	54	34.3	a 0.093	1.86	0.247	533	28800	762	7.86
			b 0.251	1.25	0.490	10264	28800		-

*/ The time of maximum capillary rise for all aggregates was assumed at 24 h (86 400s)

The ability to create secondary aggregates under the influence of dynamic and static action of water constitutes a very important property of soil aggregates. In the case of this assessment, it is not only the degree but also the character of this degradation (i.e. percentage content of individual fractions of secondary aggregates) that is important. In order to better illustrate the consequences of the dynamic and static water action, this time the research results were presented not in a table but graphic form (Fig. 1). Owing to a very large number of measurement combinations and considerable fraction variability, the analysis of the graphic content was limited to the most important generalisations. The capacity of the examined soils for aggregate formation depended on: the texture, humus content as well as the moisture and density of primary aggregates. The above-mentioned traits precondition, complement or substitute one another and form specific, characteristic only for one soil, micro- and macrostructural complexes [1, 3, 5]. Therefore, frequently soils which are very similar with respect to their properties behave quite differently under the influence of the dynamic or static water action. The most important role in this respect is played by soil graining on which the intensity of action of the remaining structure-forming factors depends. In general, the examined soils were characterised by high aggregation as it was contained within the interval from approximately 40% to over 90% of secondary aggregates larger than 0.25 mm accompanied by a simultaneous considerable fraction diversification.

A 10-degree classification was employed to assess the water resistance of the examined soil aggregates (Tab. 1). According to the applied classification, the experimental soils exhibited different degrees of water resistance which ranged from extremely low (1st degree) to extremely high (9th degree) when the action of water was dynamic and from very small (2nd degree) to full (10th degree) - at the static action of water. A much more favourable results emerged of the secondary aggregation index, also expressed in a 10-degree scale. The capacity for the secondary aggregation of the examined soils ranged from 4 (small) to 9 (extremely high) degrees in the case of the dynamic water resistance and between 5 (medium) and 8 (very high) degrees in the case of the static action water.

In order to obtain a comprehensive characterisation of the effect of the aggregate structure on the development of the soil climate, in particular, on the soil water properties, it

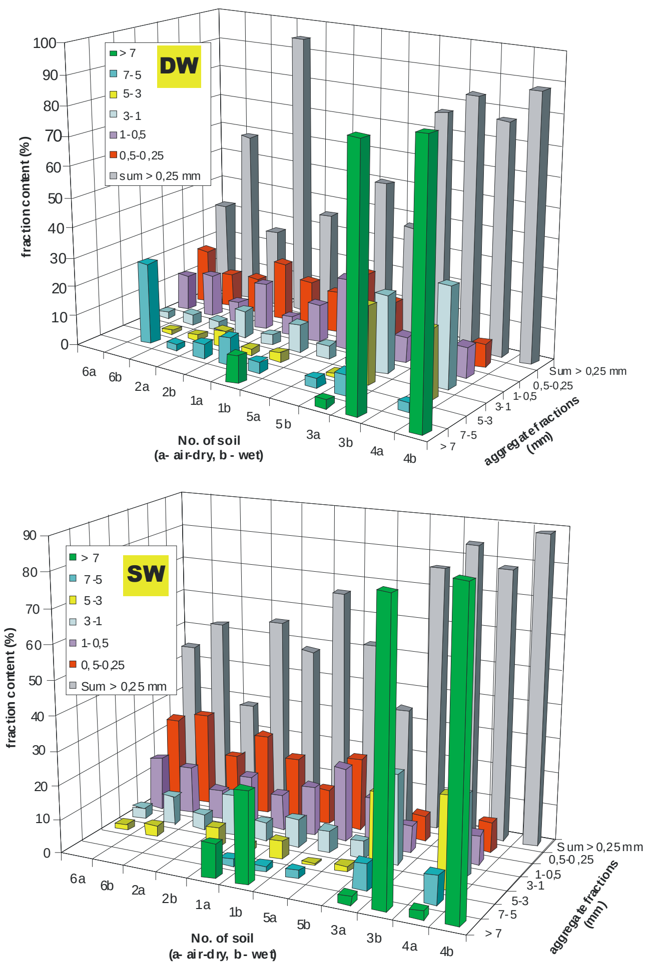

Fig. 1. Secondary aggregation after dynamic (DW) and static (SW) water action for air-dry (a) and wet (b) soil aggregates

is essential to have sufficient information about such parameters as the speed of the water movement in the soil aggregate as well as its capillary water capacity [1, 13]. Table 2 and Figure 2 present the research results which reveal specific, complex and very diverse behaviours of the examined soil aggregates during the process of their moistening. The speed of the capillary rise determined in the air dry aggregates varied quite significantly from 68 s to 1180 s. This was, undoubtedly, influenced by the aggregate structural setup determined by density or porosity, i.e. properties which depend on the soil texture but, at the same time, strongly modified by the humus content (Table 2). This variability in the speed of water movement in the aggregates, both in the case of the minimum and maximum capillary rise (4 hours), resulted in significant differences in the amount of water which the aggregates were able to absorb. The minimum capillary water capacity ranged in the interval 0.281 – 0.664 $m^3 \cdot m^{-3}$, but it was distinctly lower in wet aggregates than in the air dry ones (Fig. 2). Even greater differences occurred in the maximum capillary water capacity where the quantity of the absorbed water ranged from 0.332 – 1.035 $m^3 \cdot m^{-3}$.

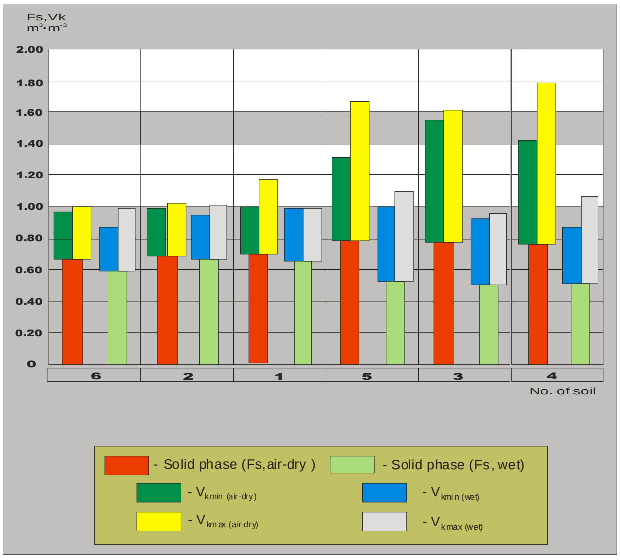

Fig. 2. Minimum (Vk min) and maximum (Vk max) capillary water capacity of soil natural aggregates

It is easy to notice that the amount of water absorbed by the aggregates during capillary rise, both the maximal and minimal, exceeded their initial porosity in the majority of cases. This means that the aggregate had to increase its initial volume (1 cm^3). This increase of the aggregate primary volume leads to what is often called unlimited swelling (Fig. 2). This unlimited, triaxial aggregate swelling occurred at a very wide value interval ranging from several to several dozen percent achieving, in the case of maximum swelling, the aggregate volume increases of up to 80% in air dry aggregates of the soil No. 4.

Aggregate shrinkage taking place as a result of their drying is a process antagonistic in relation to swelling [1, 6]. This phaeozems property also exhibited a considerable value diversification and ranged from 0.0 to 50% (Fig.3). Aggregate shrinkage caused bulk density after shrinkage to increase very rapidly, as evidenced by the values in Tab. 2. In this situation, total porosity was found to decline causing considerable changes in the pore structure.

The observed strong compaction of soil aggregates during their shrinkage resulted in their increased compression strength [1, 10]. In the analysed phaeozems aggregates, their resistance to external strains ranged from 0.82 to 7.86 MPa and depended, primarily, on soil graining.

From among the six analysed phaeozems, the soil designated as No. 5 deserves special attention. Despite its considerable coloid fraction content (24%), it was characterised by very low structure-forming parameters. This can be attributed to the fact that this soil contained over 50% of silt fraction (0.05 to 0.002 mm), i.e. approximately two times more than in the remaining soils. Therefore, it can be said that an earlier observed regularity [1, 5, 12] that soils containing high levels of the silt fraction are characterised by low water resistance, poor secondary aggregation and small resistance to compression was also confirmed by this study. This fact, however, does not disqualify these soils agriculturally because high levels of the silt fraction exert a favourable influence on the air-water properties of such soils, due to the fact that they maintain high porosity for a long time and are characterised by high water retention potentials [1, 11, 13].

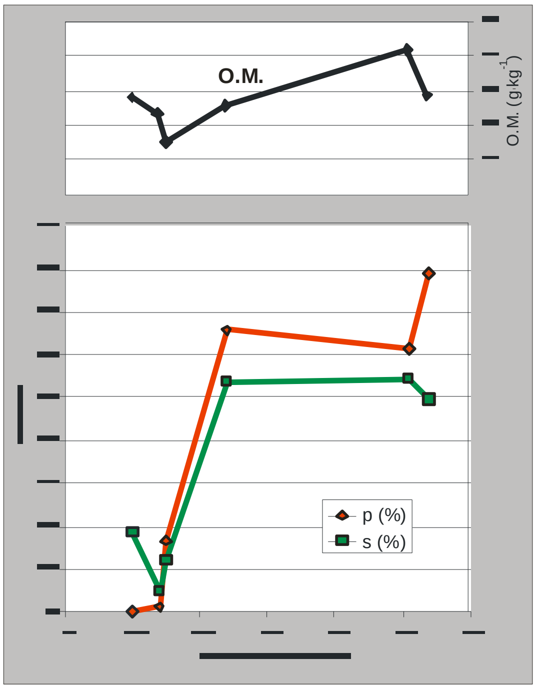

Fig. 3. Swelling (p) and shrinkage (s) of soil aggregates in relation to content of colloid fraction (< 0,002 mm) and organic matter (O.M.)

Recapitulation

The soil aggregate structure, and this also refers to the aggregate structure of phaeozems, constitutes only a certain, on the whole, transitory phase and changes into permanent coherent structures. In practice, it is a type of structure characteristic to the soil surface horizons, i.e. the topsoil. It is exactly this horizon that, following various tillage operations, unique granular, crumbly structures develop which possess properties essential for plant development. One of the more important properties of the aggregate structure is the resistance of aggregates to the action of water, the so called water resistance. It is not the energy or the period of time necessary to break down these aggregates completely that is essential in this particular property, but it is rather the effect of their action that matters, in other words, the quantity and quality of the developed aggregate fractions, the so called secondary aggregation.

The action of water in the process of destruction of the soil aggregate structure may take either a dynamic or static form; in the case of a rainfall, both these processes occur side by side. The resistance of the aggregate structure to the dynamic and static action of water is undoubtedly an important characteristic, nevertheless, it can provide only a fragment of the soil structure assessment from the point of view of the agrotechnical properties of arable soils. This can be attributed mainly to the temporary character of the complete aggregation in the arable-humus horizon and to the possibility of macro-aggregate structures passing into micro-aggregates structures which remain highly porous. Both water resistance itself as well as the degree and character of the macro-aggregate degradation into smaller fractions depend on soil properties, in particular, on its texture and on the strongly modifying impact of organic matter.

Among the most important properties of soil aggregates is their capability for swelling and shrinkage under the influence of soil moisture changes which take place during wetting or moistening processes. Both swelling and shrinkage of soil aggregates should be considered as processes capable of self-regulating their mutual proportions in the three-phase soil system which have a beneficial influence on the exchange of the gaseous phase and on the increase of water capacity. All in all, they affect the development of optimal air-water properties both in soil aggregate and in the entire horizon topsoil.

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