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RESISTANCE OF SOIL AGGREGATES TO DYNAMIC AND STATIC WATER ACTION IN POLISH SOILS

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A b s t r a c t. The paper presents the most significant results of a five-year research project aimed at examining the aggregate water stability of the main types, kinds, and genera of Polish soils. The investigations included 55 soils representing the main soil textures in Poland. Soil aggregates of a structure, compactness and moisture found in natural conditions were analysed as well the aggregates that were moulded in the lab at controlled conditions of compaction and moisture according to procedures elaborated earlier [3]. Detailed investigations focused on 1 cm^3 cylindrical aggregates cut out from natural soils and from soils artificially prepared. The stability of soil aggregates in dynamic and static action of water was analysed and the measurements of a secondary aggregation following that analysis were performed.

It was found that soil aggregate resistance to dynamic and static action of water depends, above all, on the soil mechanical composition, mainly on the content of clay fraction. Sometimes a significant effect is also exerted by the content of silt and sand fractions as well as the content of humus. Differences between the aggregates of sandy and clay soils can reach the relation of 1:1 000. The resistance of moist aggregates appeared to be several dozen times higher than that of air-dry aggregates. Water stability of soil aggregates also depends on the degree of their compactness. For structure assessment secondary aggregation also seems to be a very important feature as well as the state of a high and relatively stable porosity.

INTRODUCTION

In 1990, a 5-year research project was completed. The project was aimed at examining the state, abilities and structure-forming properties of the main soil textures in Poland. In the study, the concept of structure was not limited to aggregation; it was interpreted as a more complex concept of the three-phase soil system. Structure in this sense undergoes changes in the course of time and is determined by the size, shape and complexity of particular granules, particles or aggregates making up the mineral and organic components of the soil [2]. Such an interpretation of the soil structure is in accordance with the definitions suggested by Brewer and Sleemen [1]. The basic structural types are as follows: cohesive, aggregate, single-grain as well as some transitional (mixed) structures that occur between these types. More detailed distinctions or definitions are: the aggregate structure, the structure of the arable layer or genetic horizon, and the structure of soil profile. The present paper focuses on the analysis of the aggregate and cohesive structures in the arable layer of Polish soils. Many studies aimed at developing experimental methods, definitions, classifications and interpretations of this soil structure [2] have preceded these investigations of the state of Polish mineral soils including studies on physical properties such as water resistance. Moreover, several methods were devised to analyse a number of important properties of soil structures that were compacted both in nature and in the laboratory [3,4].

Soil structural investigations that have been carried out at Poznań for many years have proven to be fundamentally different from those conducted at other research centers. Here structure has a broader meaning and does not concentrate on only aggregation or microstructures. This different approach causes limitations on the methods of investigations that have been used until now. In the initial stage of our investigations, we applied analytical methods which were known at the time. However, faced with their limited applications and suitability, we focused first of all on experimental methods which would enable us to carry out many-faced, joint, verifiable and comparable analyses of different soil structures, including aggregation and cohesion.

Finding the ability of water to compact soil and using it proved to be a turning point in search for new methods. As it is generally known, water plays a fundamental role in the compaction process. At the solid-liquid interphase, where there is an enormous specific surface area, a mutual interaction occurs which has the potential to form strong, stable, structural bonds. However, the gaseous phase may significantly reduce or eliminate the tendency of water to compact the soil.

Our experimental methods also pointed out that it is possible to mix liquid and gaseous phases using amounts that will give simple, verifiable, reproducible and comparable results. Thus, it was possible to achieve different states of compaction or loosening for the soils that were investigated. It should be emphasized that soil water not only causes compaction but also forms the soil structure (the soil's internal composition) according to the laws of physics.

Making use of these facts, methods were devised to investigate soil structures for different compactions, porosities, arrangement, moisture etc. These results were presented in detail in two publications on methodology [3,4]. These methods were used to obtain a wide variety of results which characterized, among other things, soil structural resistance to the dynamic and static action of water and secondary aggregation.

MATERIALS AND METHODS

The investigations included 55 soils representing the main soil textures in Poland. Locations of soils investigated are shown in Fig. 1; differences in texture are shown in Fig. 2. Table 1 shows the basic physical and chemical properties as well as taxonomic definitions of the soil units investigated.

Detailed investigations focused mainly on arable layers of cultivated soils. Cylindrical aggregates of 1 cm^3 (base surface =1 cm^2, height =1 cm) were analysed from bulk samples.

A sampler was used to cut aggregates out of arable layers that were characterized by their natural compaction, structure and moisture; some samples were at moisture contents of field capacity [3]. The field experiments and sampling were carried out at the end of August and beginning of September 1986, 1987 and 1988 when the arable layer was homogeneous and relatively strongly compacted (frequently approaching the maximum). The bulk samples could be regarded as volumetric samples representing the natural structure, porosity, compaction and moisture of the arable layer as well as aggregates of natural structure, having a definite shape and volume.

Bulk samples characterized by natural moisture (*Wn*) and moisture contents at the field capacity (*Wp*), underwent tests with dynamic and static water action. Measurements were repeated after air drying of the samples. The resistance of aggregate breakup to dynamic water action (*DW*) was determined by the use of the ADWA device, whereas resistance to the static action (*SW*) used the WSW device [3]. Following these analyses secondary aggregation was determined on 7.0, 5.0, 3.0, 1.0, 0.5 mm sieves. Since there was a large amount of data, the results of secondary aggregation were given as a sum of

Fig. 1. Location of soil profiles.

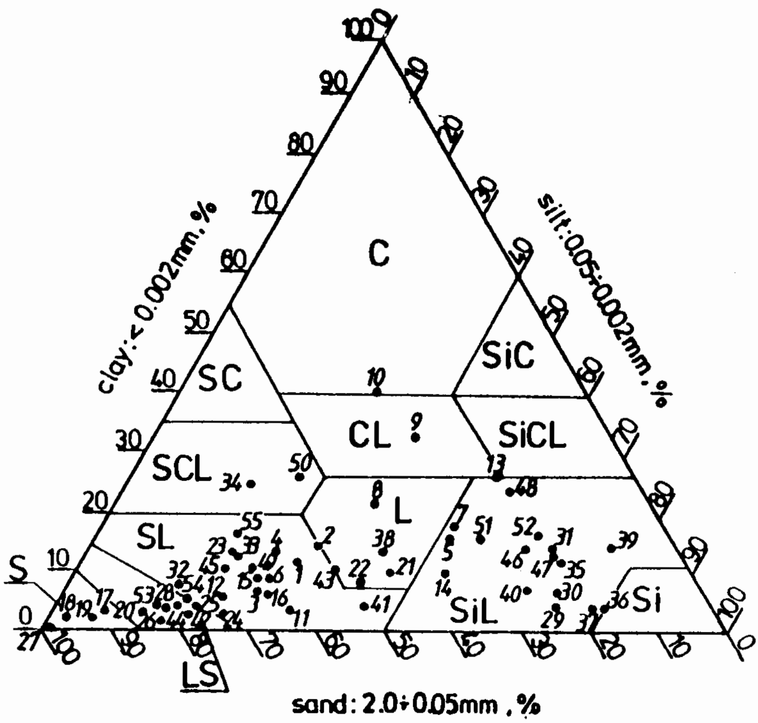

Fig. 2. Texture of investigated soils.

Table 1. Parent materials, genetic types and texture of investigated soils

Soil group	Parent material of soils	Soil profile Nos	Soil genetic type	Soil texture (acc. to Fig. 2)	Organic matter (%)
A	Alluvial and deluvial sands	17-20, 27	Alluvial soils, mucky soils	S, LS	0.86 - 2.95
B	Deposits of Würm glaciation	1-4, 11, 12, 15 54, 55	Lessive soils, black earths	SL	0.80 - 3.90
C	Deposits of Riss glaciation	23-26, 42, 44 45, 53	Brown and lessive soils, black earths	LS, SL	1.00 - 3.10
D	Deposit of Günz glaciation	51	Black earth	SiL	3.60 - 3.80
E	Carpatian flysch	47, 48	Brown soils	SiL	1.65 - 1.85
F	Loess	13, 14, 21, 22, 29-31, 35-37, 39, 40, 46, 52	Brown, lessive, chernozem soils	SiL, SL, L	1.26 - 4.78
G	Alluvial deposits	5-8, 16, 41, 43	Alluvial soils	SL, SiL, L	1.40 - 3.10
H	Craetaceous and Jurassic limestones	28, 32-34, 38, 49, 50	Rendzinas	LS, SL, SCL, L	1.12 - 3.17
I	Interglaciation clays	9, 10	Black earths	CL	2.80 - 4.00

unwashed secondary aggregates with diameter >0.5 mm. These include coarse sand (0.5-1.0 mm). The same procedure was used to analyse aggregates at 5 different compaction and porosity states obtained in the laboratory by adding suitable amounts of compacting water to the air-dry soil which had been sieved through a 1 mm mesh sieve. In this case, the soil aggregates were characterized as highly moulded with strictly controlled porosity and moisture, the most essential parameters of the cohesive and the aggregate structures.

RESULTS AND CONCLUSIONS

Tables 2 and 3 present the most significant results from the investigations of soil aggregate resistance to dynamic and static water action. The results shown are limited to the analysis of only one state, maximum compaction, which is attained at a standard compacting moisture content (*Wsz*) [3]. Four other compaction states, attained at different amounts of compacting water (*Wz*), both greater and less than *Wsz*, were not included in this paper. For the same reasons, we excluded the results obtained in studies on water resistance and secondary aggregation following freezing. Out of several thousand results, only the most important ones were included in this paper in the form of generalized values (Table 2) or means of five measurements (Table 3).

Table 4 shows results obtained in the measurements of soil aggregate resistance to the dynamic (*DW*) and static (*SW*) water action and measurements of secondary aggregation. The table also presents basic

Table 2. Mean values of soil aggregate properties (55 soils)

Property of soil aggregate*	Symbol	Unit	Soil aggregate compacting moisture					
			Natural (Wn)		Field capacity (Wp)		Standard (Wsz)	
			a **	b	a	b	a	b
Resistance of soil aggregate to dynamic water action	DW	$E=10^{-2}$ J	112	15	151	14	142	26
Resistance of soil aggregate to static water action	SW	Time=h	15	5	14	4.5	8.5	0.7
Resistance grade of soil aggregate to DW	G_{dw}	-	5.15	2.95	5.50	2.70	5.45	3.60
Resistance grade of soil aggregate to SW	G_{sw}	-	8.75	6.20	8.80	5.95	6.80	4.15
Index of secondary aggregation after DW	I_{dw}	% aggregate > 0.5 mm	48	24	55	24	41	22
Index of secondary aggregation after SW	I_{sw}	% aggregate > 0.5 mm	61	32	67	26	56	30
Degree of secondary aggregation after DW	G_{Idw}	-	5.25	3.65	6.00	3.05	4.80	3.40
Degree of secondary aggregation after SW	G_{Isw}	-	6.50	4.10	6.95	3.55	6.15	3.80

* Degrees and indices according to the classification in Table 3; ** a - moist aggregates; b - air-dry aggregates.

Table 3. Classification of resistance of soil aggregates and secondary aggregation to dynamic and static water action

Degree of water resistance (G_{dw}, G_{sw}) and secondary aggregation (G_{dw}, G_{sw})	Name of water resistance (DW, SW) and degree of water resistance (G_{dw}, G_{sw})	Dynamic water resistance (DW): Quantity of standard drops	Dynamic water resistance (DW): Kinetic energy (x 10^{-2} J)	Static water resistance (SW) (desintegration time in s, min, or h)	Indices of secondary aggregation (I_{dw}, I_{sw}) (%)
1	Extremely low	< 40	< 2	< 40"	< 5
2	Very low	40 - 100	2 - 5	40" - 1'30"	5 - 10
3	Medium low	100 - 200	5 - 10	1'30" - 3'	10 - 20
4	Low	200 - 500	10 - 25	3' - 8'	20 - 35
5	Medium	500 - 1 000	25 - 50	8' - 15'	35 - 50
6	Medium high	1 000 - 2 000	50 - 100	15' - 30'	50 - 65
7	High	2 000 - 5 000	100 - 250	30' - 1h30'	65 - 80
8	Very high	5 000 - 10 000	250 - 500	1h30' - 6h	80 - 90
9	Extremely high	10 000 - 20 000	500 - 1 000	6h - 24h	90 - 100
10	Full	> 20 000	> 1 000	> 24h	100

indices and degrees of secondary aggregation. Natural, field capacity, and standard moisture contents were analysed for all samples. Analysis included moist and air-dry aggregates.

Results presented in Table 2 show that moist and air-dry aggregates compacted in the laboratory have similar water resistances to those found for natural aggregates

Table 4. Resistance of soil aggregates to dynamic (DW) and static (SW) water action and their secondary aggregation

Soil No.		Fractions (%) I	Fractions (%) II	Organic matter	Porosity (Pc)	DW $E=x\,10^{-2}$ J a	DW $E=x\,10^{-2}$ J b	Secondary aggregation after DW (%) a	Secondary aggregation after DW (%) b	SW (s) a	SW (s) b	Secondary aggregation after SW (%) a	Secondary aggregation after SW (%) b
		mm	mm	%	%	a	b	a	b	a	b	a	b
	1	2	3	4	5	6	7	8	9	10	11	12	13
A	27	0	1	2.95	32.2	13.30	2.20	33	19	86400	105	81	22
	18	2	3	0.86	40.5	1.10	1.30	2	1	85	76	2	2
	19	2	7.5	2.86	37.2	1.60	1.40	3	3	60	20	5	4
	17	3	8	1.38	32.6	1.40	1.20	12	10	56	22	10	9
	20	3	13	2.58	40.6	11.00	2.20	21	7	2194	40	41	10
B	11	3	35	0.89	32.0	4.70	1.90	3	9	69	13	7	6
	54	5	19	1.91	23.7	22.50	18.30	9	8	220	35	16	11
	12	5	23	0.84	28.4	5.20	2.00	4	11	73	35	10	7
	3	6	28	2.22	30.5	4.00	2.40	10	37	122	50	22	6
	15	9	27	2.10	39.2	32.90	4.90	58	31	14400	120	2	10
	1	11	31	1.98	32.7	29.90	5.10	21	8	14400	7200	61	47
	4	13	28	2.29	40.4	29.40	4.20	33	14	14400	115	37	25
	2	14	33	2.17	38.8	25.50	4.70	19	5	14400	100	61	14
	55	16	20	3.86	29.6	50.00	5.30	34	8	28800	48	86	35
C	26	1	17	1.40	30.7	9.80	2.40	13	11	614	35	23	11
	42	3	20	0.95	24.5	24.50	15.00	8	8	70	33	11	8
	24	3	24	1.05	30.5	6.70	2.40	11	10	1237	30	16	11
	53	4	14	1.64	26.6	27.90	16.20	11	12	72	30	15	13
	44	4	18	1.47	24.3	161.90	22.80	8	10	21600	88	20	8
	25	4	20	1.34	32.9	5.40	2.00	10	9	273	18	14	9
	23	10	21	3.10	38.8	264.40	4.20	53	10	86400	146	74	13
	45	12	21	1.66	27.5	107.90	57.90	11	9	10900	152	25	10
D	51	16	57	3.65	44.9	122.60	13.70	48	15	28800	381	100	36
E	47	12	69	1.86	33.9	169.70	48.60	3	2	2175	142	14	2
	48	24	56	1.65	36.3	328.60	130.50	16	22	14400	850	66	43
F	29	4	72.5	2.02	43.9	5.60	2.10	2	1	319	33	3	2
	37	4	78	2.90	39.8	8.30	3.30	15	6	295	110	5	2
	36	4	79	2.62	40.3	6.80	3.70	17	7	446	20	21	4
	30	7	70.5	2.81	44.8	15.70	2.20	2	1	198	33	5	2
	22	8	43	2.37	39.5	33.70	4.60	18	4	380	65	36	4
	40	8	67	2.32	32.5	58.80	31.40	1	1	305	97	8	2
	21	10	46	2.19	37.3	28.70	3.90	18	1	511	68	33	3
	14	10	53	2.58	38.7	41.70	7.90	11	44	7260	150	44	7
	35	11	70	1.26	45.5	22.50	20.10	2	3	437	40	4	1
	46	13	64	1.60	35.9	25.20	14.70	2	3	2120	62	6	3
	31	14	67	4.78	44.3	39.60	4.60	35	4	28800	166	70	20
	39	14	75	1.43	36.5	54.00	23.00	2	1	625	95	7	1
	52	16	64	1.86	32.8	161.80	73.00	2	1	1240	235	60	22
	13	26	53	3.02	36.9	245.30	39.20	93	60	14400	14400	3	62

	1	2	3	4	5	6	7	8	9	10	11	12	13
G	41	4	45	3.08	33.3	17.70	5.40	16	5	2664	144	24	11
	16	6	30	2.76	43.9	335.50	4.40	51	12	86400	160	61	18
	6	8	28	1.46	30.4	7.40	3.40	4	6	295	86	22	4
	43	10	37	2.33	33.3	158.90	26.50	67	24	28800	1678	100	76
	5	16	51	2.40	37.7	49.00	15.20	46	29	14400	660	65	59
	7	17	51	2.59	41.4	58.90	44.10	25	54	14400	14400	82	70
	8	21	38	2.02	44.4	245.30	11.80	66	34	14400	600	79	60
H	28	4	16.5	2.03	33.5	28.70	3.50	19	14	310	65	21	12
	32	8	15	1.12	34.1	22.60	10.00	22	18	28800	681	84	76
	49	10	25	2.75	32.1	235.40	4.40	80	30	28800	1270	99	66
	33	12	21	2.46	41.4	309.00	3.70	51	14	28800	102	67	74
	38	13	43	2.33	32.4	225.60	26.50	100	32	28800	1093	100	70
	34	25	18	3.10	46.4	176.60	6.20	100	53	28800	759	100	22
	50	26	24	3.17	38.8	250.20	9.30	20	36	28800	69	100	73
I	9	33	38	4.01	46.2	245.30	21.10	96	40	4400	581	77	60
	10	40	29	2.81	41.3	245.30	15.20	96	27	4400	537	77	46

I - soil fraction < 0.002 mm; II - soil fraction 0.05-0.002 mm. For other explanations see Tables 1-3.

having a comparable moisture content at the time of measurement. This has also been confirmed by calculated coefficients, degrees of water resistance and secondary aggregation [3]. However, moist and air-dry aggregates compacted in the laboratory showed, on the average, a higher resistance to the static water action (*SW*) since there was no soil binding by small plant roots which frequently increased the time of disintegration of natural aggregates. In general, however, water resistance, secondary aggregation and other physical properties of structures from natural conditions and modelled in the laboratory were found to have similar values. This principle, confirmed by results from comprehensive studies, makes it possible to investigate soil structures having different moisture contents, compaction and porosity within moulded aggregates. The physical and chemical properties of aggregates and other structures can be modelled and controlled under laboratory conditions. Table 3 shows these research possibilities and their results which can be generalized and summarized in the following way.

1. Resistance of soil aggregates to dynamic water action (*DW*) depends mainly on the soil's texture, primarily on the percentage of clay (<0.002 mm), and then on the amount of silt and sand. As the clay fraction increases from, e.g. 1-3 % to about 20-40 %, the water resistance of moist aggregates can increase by 200-300 times (e.g., soils No. 18 and No. 48 in Table 4). In extreme cases, the increases can be 1 000 fold. A high content of silt (over 50 % fraction 0.05-0.002 mm) acts to diminish the water resistance of aggregates (e.g., in loesses and cohesive alluvial soils, etc). In aggregates having a relatively small silt content (below 30 %), the water resistance is usually high. A markedly higher water resistance is displayed by aggregates of both a relatively high humus content and a low porosity (strongly compacted).

2. Resistance of moist aggregates to dynamic water action is usually up to several dozen times higher than that of air-dry aggregates. Such differences are not seen in sandy soil aggregates with relatively low humus content and low water resistance for moist soiis.

3. Soil aggregate resistance to static water action also depends on mechanical composition of the soil; however, the effect of the colloidal clay proves to be significantly smaller when compared with dynamic water resistance. A stronger influence is exerted here by humus content, sand granulation,

aggregate compaction, than by clay, etc. Water resistance is up to a few hundred times larger in moist aggregates than in the air-dry ones. Aggregates of very cohesive soils may not always show these differences.

4. Soil aggregate resistance to dynamic and static water action is usually up to several times higher for the case of strongly compacted aggregates when compared with weakly compacted aggregates (relatively high porosity).

5. The tendency to form secondary aggregation under the influence of dynamic and static water actions proves to be a very important property of soil aggregates. Under conditions of secondary aggregation, soil porosity remains relatively high. Soils formed from limestones (rendzinas) and some black earths show a particularly stable secondary aggregation. The secondary aggregation of cohesive soils is significantly increased by freezing and thawing of moist soils.

6. In the agricultural evaluation of soil structures, it is essential to consider not only the aggregate water resistance (loesses, alluvial soils, etc., have relatively low water resistance) or even the high secondary aggregation, but above all, the duration of high porosity, including the high porosity of particular aggregates as well as aggregate and monolithic structures. This issue will be presented in a forthcoming publication.

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ODPORNOŚĆ AGREGATÓW GLEB POLSKI NA DYNAMICZNE I STATYCZNE DZIAŁANIE WODY

W pracy przedstawiono najistotniejsze wyniki pięcioletnich badań wodoodporności struktury agregatowej najważniejszych typów, rodzajów i gatunków gleb Polski. Analizowano agregaty glebowe o strukturze, zagęszczeniu i wilgotności naturalnej oraz agregaty o strukturze, zagęszczeniu i wilgotności kształtowanej oraz ściśle kontrolowanej w warunkach laboratoryjnych. Badania 55 reprezentatywnych gleb z różnych rejonów Polski przeprowadzono wg metodyki opracowanej i opublikowanej przez autorów [3]. Obiektem badań były agregaty wycinane z gleb o strukturze naturalnej i modelowanej, o objętości 1 cm^3. Analizowano odporność agregatów glebowych na dynamiczne i statyczne działanie wody, a także agregację wtórną, powstałą po dynamicznym i statycznym działaniu wody. Stwierdzono, że odporność agregatów glebowych na dynamiczne działanie wody zależy przede wszystkim od składu mechanicznego gleby, głównie od frakcji iłowej. Istotny wpływ wywiera niekiedy zawartość pyłu i piasku, a także próchnica. Różnice pomiędzy agregatami z gleb piaszczystych i ilastych mogą osiągnąć relacje jak 1:1000. Odporność agregatów wilgotnych okazała się od kilku do kilkudziesięciu razy wyższa niż agregatów powietrznie suchych. Wodoodporność agregatów zależy również od stopnia ich zagęszczenia. Dla oceny struktury gleby ważną właściwością jest także jej agregacja wtórna, przede wszystkim jednak stan wysokiej, względnie trwałej porowatości.