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WATER RESISTANCE OF THE RENDZINAS STRUCTURE OF DIFFERENT GEOLOGICAL FORMATIONS

W. Spychalski, A. Mocek, W. Owczarzak

Department of Soil Science, August Cieszkowski Agricultural University
Mazowiecka 42, 60-623 Poznań, Poland

Abstract. The basic objective of the research was to investigate and determine variations in the physico-chemical properties of the arable layer (Ap) of calcareous soils which belong to the group of lithogenic soils. The above objective was achieved by determining the following physical soil parameters: static and dynamic water resistance of soil aggregates as well as the state of their secondary aggregation following static and dynamic action of water. The above mentioned physico-mechanical properties were determined for wet aggregate models, wet aggregate models subjected to freezing and defreezing and dry "ones", i.e., brought from the appropriate level of moisture to the air-dry state.

In order to obtain a comprehensive picture of the properties analysed in the study and their complex evaluation, samples were collected in such a way as to represent the most important and common groups of Rendzinas occurring in Poland. Hence, the material sampled for laboratory analyses developed from various parental rocks.

Keywords: rendzinas, structure, dynamic and static resistance.

INTRODUCTION

In the Polish pedological literature numerous papers on rendzinas can be found [1-4]. Majority of Rendzinas can be classified as two-level soils whose agricultural value depends primarily on the thickness of the humus horizon as well as the depth and degree of weathering of the parent rock. These properties make them distinctly different from other systematic units. Therefore, in the pedological studies on Rendzinas, special attention should be paid to the properties characterising upper levels. A property which characterises the state and variability of the above mentioned level in a complex way is its structure, a trait which is a function of texture, quantity and character of organic matter as well as calcium compounds varying in regard to their quantity and quality.

No detailed studies on this property made the present authors carry out investigations concerned with structure analyses of the soils which develop both in natural environment but which are also formed in laboratory conditions allowing the control of many parameters characterising variability and stability of aggregate structures.

MATERIALS AND METHODS

Analyses were performed on soil aggregates compacted and formed in laboratory at five states of wetting. The above mentioned physico-mechanical properties were determined both for models of wet aggregates, wet aggregates subjected to freezing and de-freezing processes as well as of dried aggregates, i.e., brought from the appropriate state of wetting to the air-dry state. The scope of the above mentioned physico-mechanical parameters of model structures comprised the formation of about 6000 soil aggregates with the volume of 1 cm^3 each. In order to obtain a comprehensive picture of the properties analysed in the paper which would allow their complex evaluation, the samples were selected in such a way as to represent the most important and frequently occurring types of Rendzinas found in Poland. That is why the soil material sampled for laboratory analysis was formed from different parental rocks. Calcareous soils selected for investigations are situated in the south-eastern part of Poland, in various geographic regions [1]. Details concerning distribution of the examined soils are presented in Table 1.

In order to characterise physical and chemical properties of the examined soils, the following properties were determined using widely accepted methodology [5]: texture composition using the method of total analysis - TA [6], moisture content, specific and bulk densities, porosity, pH, total nitrogen, organic carbon and carbonates.

Investigations of dynamic and static water resistance were carried out using methods developed in the Department of Soil Science of the Poznań Agricultural University [7,8]. Comprehensive results of research of these properties were presented

Table 1. The localization of investigated profiles

Locality	Profile No.	Geographic region	Geological formation
Józefów	1,2	Pagóry Chełmskie	Cretaceous rendzinas
Strzelce	3	Działy Grabowieckie	Cretaceous rendzinas
Kąty near Zamość	4,5	Roztocze Środkowe	Cretaceous rendzinas
Świeciechów on the Vistula	6	Wzniesienia Urzędowskie	Cretaceous rendzinas
Chęciny	7	Góry Świętokrzyskie	Cretaceous rendzinas
Gacki near Pinczów	8,9	Niecka Nidzianska	Devonian rendzinas
Piaski	10	Wyżyna Częstochowska	Gypsum rendzinas
Przymiłowice	11	Wyżyna Częstochowska	Jurassic rendzinas

elsewhere [10]. The current study presents only some fragments and the most important results revealing the nature and extent of the aggregate water resistance in the modelled structure in the conditions of strictly controlled compaction and formation moisture content at five states of wetting soil compaction. The following parameters were determined for the aggregates formed in this way:

Dynamic water resistance (DW) using the "ADWA" apparatus, i.e. analyser of dynamic water resistance of aggregates [7,8]. The apparatus is equipped in a device which allows to apply water droplets of 0.05 ml volume falling from the height of 1 m and striking the aggregate surface with the kinetic energy of 4.905×10^{-4}J. The above analysis was performed for wet (A), air-dry (C) and wet aggregates after freezing (B). The process of triple freezing/de-freezing consisted in placing aggregates in a freezer at the temperature of –10 ^{0}C for the period of three hours and then de-freezing them at the temperature of +18 ^{0}C. The result indicating the resistance of aggregates to the dynamic action of water was determined as a mean from 5 repetitions and expressed as the quantity of standard drops or in values of kinetic energy.

Static water resistance (SW) determined using the WSW apparatus [7,8]. The device consists of a rectangular vessel made of organic glass in which two nylon threads are stretched along longer sides. The threads are placed parallelly at one level 6 mm apart. Water resistance of the aggregates to static action of water is estimated by measuring the "time of wetting" of aggregates submerged in water. For this purpose, 5 aggregates were placed on the stretched nylon threads at the distance of 10 mm from one another and then the vessel was filled with water to the height of a few mm above aggregates. The wetting time was calculated from the moment of water contact with aggregates until the moment when, after destruction, they fell down to the bottom of the vessel. The result was determined as a mean from five repetitions and expressed in seconds.

The complete and precise evaluation of soil aggregate resistance to dynamic and static action of water requires determination of the extent of destruction as well as determination of the quantity and quality of the developed secondary aggregates (Adw, Asw). This analysis was carried out using a sieve method [7]. For this purpose, the residues obtained from the determination of dynamic and static water resistance were transferred onto a set of 7; 5; 3; 1; 0.5 and 0.25 mm sieves. The sieves were then submerged in water where the aggregates were segregated into fractions. Aggregates from individual sieves were collected into evaporating dishes, dried, weighed and then percentage contents of individual secondary aggregates were calculated.

RESULTS AND DISCUSSION

Texture composition of Rendzinas depends on the type of parent rock, its mineralogical composition and the amount of non-soluble, frequently foreign admixtures of sand, silt and loam fractions. With regard to their texture, the upper layers of the examined Rendzinas show a considerable variation ranging from medium sands to silty-clayey loams (Table 2).

Table 2. Grain size distribution of investigated soils

Profile No.	Depth (cm)	Fractions - %				Textural group acc. to Polish Soc. Soil Sci. (PTGleb)
		2.0-0.1	0.1-0.02	<0.02 mm	<0.002	
		(mm)				
1	0-28	20.28	20.99	58.73	22.06	gc
2	0-25	46.47	33.04	20.49	10.24	gl.sl.sp.p
3	0-20	35.26	28.10	36.64	20.21	gs
4	0-24	23.92	27.49	48.59	29.71	gcp
5	0-20	26.51	22.85	50.64	37.39	gc
6	5-20	63.14	16.86	20.10	12.73	gl.s.sp.p
7	5-20	68.07	15.59	17.74	9.53	pgm
8	0-20	42.48	12.89	44.63	16.79	gs
9	5-20	45.98	20.36	33.66	21.04	gs
10	5-10	54.40	11.76	33.84	21.34	gs
11	5-15	46.52	15.82	37.66	25.14	gs

In most cases, the basic chemical properties of the examined soils (pH, soil nutrient availability, humus and nitrogen content, C/N ratio) do not differ from the mean values of Polish Rendzinas given in the available soil science literature. Concentration of carbonates deserves stressing; depending on the geological origin of the rock, it ranged from 0.0 to 84.79%. On the other hand, their quantity and distribution in individual fractions of fine particles depends mainly on the character of parent rock and ranges widely (Table 3).

In the model studies of soil structures a significant role is played by the moisture content of bulk soil compaction. It is widely accepted that each soil possesses its own wetting interval allowing compaction and formation of soil aggregates [7,9]. The interval of significant effect of wetting compaction is quite wide and diversified for individual soils (Fig. 1). A characteristic value of the wetting compaction interval is, the so-called, standard wetting at which individual soils reach the highest compaction as expressed by the maximum bulk density. Water resistance of aggregates was analysed at five states of wetting compaction and the obtained results are presented in Table 4.

Table 3. Some chemical properties of investigated soils

Profile No.	Depth cm	pH H_2O	pH 1 M KCl	$CaCO_3$ %	C %	N %	C:N	O.M. %
1	0-28	8.20	7.60	50.70	2.16	0.26	8:1	3.72
2	0-25	7.90	7.50	12.28	11.40	0.76	15:1	19.65
3	0-20	8.20	7.70	11.43	1.32	0.26	5:1	2.28
4	0-24	8.20	7.50	38.94	1.32	0.19	7:1	2.28
5	0-20	8.10	7.20	5.78	1.68	0.24	7:1	2.90
6	5-20	8.20	7.60	5.57	1.20	0.15	8:1	2.07
7	5-20	8.00	7.50	0.17	0.93	0.07	13:1	1.60
8	0-20	7.50	7.10	0.33	2.76	0.30	9:1	4.76
9	5-20	6.20	5.20	0.00	1.89	0.12	16:1	3.26
10	5-10	7.60	7.00	0.40	1.77	0.19	9:1	3.05
11	5-15	7.80	7.20	2.54	2.97	0.22	14:1	5.12

Table 4. Resistance of modeled aggregates to dynamic and static water action of soil upper horizon

Profile No.	State of wetting compaction*	Compaction % w/w	Compaction % v/v	Bulk density Mg m^{-3}	Porosity Pc %	Resistance to dynamic water action ($J\,10^{-3}$) A*	B	C	Resistance to static water action time of desintegration (s) A	B	C
	I	9.67	13.93	1.44	43.53	2.31	1.91	3.73	26	26	32
1	II	17.36	25.32	1.46	42.75	2.70	5.64	4.37	115	83	23
	III	23.84	37.38	1.57	38.43	70.63	82.40	18.84	86400	86400	202
	IV	28.24	41.86	1.48	41.96	220.73	34.34	15.70	86400	86400	225
	V	33.03	44.29	1.34	47.45	90.25	14.52	15.89	86400	86400	213
	I	26.01	32.55	1.25	45.65	11.38	22.56	2.06	7080	844	8
2	II	31.60	36.56	1.16	49.57	6.23	8.04	1.91	2844	1866	12
	III	36.16	42.74	1.18	48.70	10.20	26.88	2.01	86400	598	50
	IV	38.16	44.71	1.17	49.13	39.63	62.78	2.01	86400	86400	57
	V	50.29	51.40	1.02	55.65	21.58	9.61	1.91	86400	86400	8
	I	12.59	20.43	1.62	36.96	14.22	78.48	2.50	6086	6300	37
3	II	15.86	26.44	1.67	35.02	490.50	490.50	39.63	86400	86400	506
	III	20.93	31.21	1.49	42.02	490.50	58.08	31.98	86400	86400	849
	IV	22.93	33.14	1.45	43.58	124.24	18.44	26.29	86400	86400	333
	V	27.42	38.94	1.42	44.75	68.67	3.24	28.06	86.400	456	606
	I	17.58	24.54	1.40	44.44	2.60	3.63	3.73	71	48	30
4	II	27.89	43.34	1.55	38.49	490.50	490.50	24.28	86400	86400	86400
	III	30.13	44.76	1.49	40.87	490.50	18.44	112.82	86400	86400	86400
	IV	40.09	50.36	1.26	50.00	490.50	12.75	91.58	86400	86400	86400
	V	45.41	55.55	1.22	51.59	122.63	7.01	74.95	86400	86400	86400

Table 4. continuation

Profile No.	State of wetting compaction*	Compaction		Bulk density	Porosity	Resistance					
						to dynamic water action (J 10^{-3})			to static water action time of desintegration (s)		
		% w/w	% v/v	Mg m^{-3}	Pc %	A*	B	C	A	B	C
5	I	22.90	29.82	1.30	46.94	11.77	12.36	3.14	732	1419	21
	II	30.14	45.48	1.51	38.37	490.50	441.45	32.27	86400	86400	677
	III	35.39	49.66	1.40	42.86	490.50	323.73	57.88	86400	86400	815
	IV	41.18	52.42	1.27	48.16	490.50	11.04	47.09	86400	86400	675
	V	49.31	57.43	1.16	52.65	490.50	19.42	31.00	86400	86400	553
6	I	12.15	22.20	1.83	27.95	74.95	307.64	1.77	86.400	86.400	36
	II	16.89	30.19	1.79	29.53	313.92	99.08	1.96	86400	86400	18
	III	20.45	34.11	1.67	34.25	75.54	9.71	1.52	86400	86400	6
	IV	22.96	35.72	1.56	38.58	21.19	6.47	1.67	86400	86400	6
	V	25.79	40.13	1.56	38.58	6.28	4.41	1.52	86400	86400	6
7	I	6.74	11.89	1.76	32.31	2.84	8.78	1.57	287	830	10
	II	10.38	20.58	1.98	23.85	28.65	59.11	7.06	471	86400	61
	III	12.10	23.65	1.95	25.00	59.06	119.29	7.31	5292	86400	58
	IV	12.71	23.98	1.89	27.31	23.54	4.22	5.79	7056	86400	44
	V	14.90	27.50	1.85	28.85	14.13	6.62	5.35	86400	86400	25
8	I	19.95	31.56	1.58	36.03	102.51	157.94	2.45	86.400	86.400	86
	II	26.78	42.34	1.58	36.03	490.50	215.43	3.97	86400	86400	61
	III	32.35	45.71	1.41	42.91	490.50	146.81	5.98	86400	86400	578
	IV	36.48	49.74	1.36	44.94	69.65	19.37	4.95	86400	86400	77
	V	39.85	51.89	1.30	47.37	34.34	6.18	3.58	86400	86400	43
9	I	15.38	27.03	1.76	31.78	165.45	151.07	7.65	86.400	86400	236
	II	20.90	34.69	1.66	35.66	490.50	178.54	17.46	86400	86400	3915
	III	25.06	38.65	1.54	40.31	372.78	64.75	19.23	86400	86400	3311
	IV	30.34	42.53	1.40	45.74	60.23	8.09	8.98	86400	86400	279
	V	30.44	43.65	1.43	44.57	21.39	8.19	7.95	86400	86400	94
10	I	10.66	17.16	1.61	37.84	2.40	2.70	1.32	729	86.400	2
	II	13.79	24.80	1.80	30.50	63.96	490.50	2.16	86400	86400	27
	III	19.09	33.42	1.75	32.43	490.50	490.50	4.07	86400	86400	176
	IV	21.91	36.52	1.67	35.52	387.50	166.77	3.19	86400	86400	39
	V	25.86	40.21	1.56	39.77	79.66	11.23	2.80	86400	86400	28
11	I	13.95	22.67	1.63	35.83	13.00	12.02	1.62	1186	86.400	2
	II	18.79	31.15	1.66	34.65	305.58	366.26	5.30	86400	86400	68
	III	24.71	37.66	1.52	40.16	490.50	335.50	8.34	86400	86400	82
	IV	24.37	37.93	1.56	38.58	421.83	45.22	10.10	86400	86400	280
	V	34.92	44.87	1.28	49.61	61.61	4.56	5.59	86400	86400	244

* for detail description see Material and Methods.

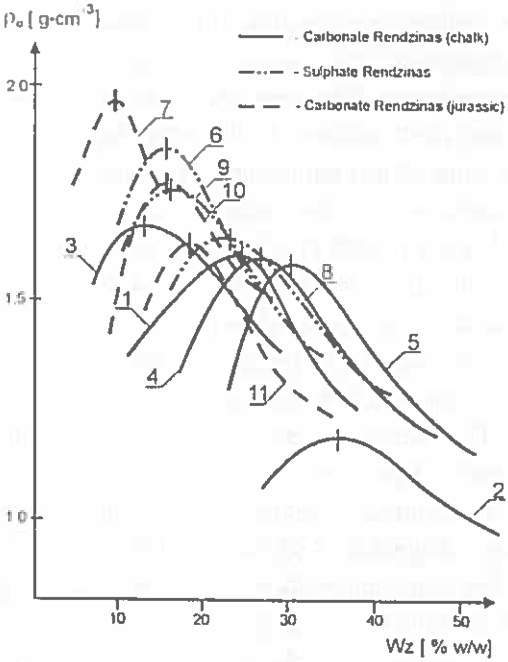

Fig. 1. Relationship between bulk density (ρo) and compaction moisture (Wz). Numbers stand for profiles number.

Aggregates subjected to the dynamic action of water showed a significantly varied water resistance. The amount of water drops necessary to break down wet aggregates completely ranged from 27 to 10000 which were converted into kinetic energy (Table 4). Differences in water resistance between individual soils, both for wet, wet frozen and air dry aggregates were so large that in the extreme cases their comparison was expressed as multiplication factors, e.g. for frozen wet aggregates the smallest resistance to the dynamic action of water (55 drops) was exhibited by aggregates collected from soil No. 10, while the highest resistance (more than 10000 drops, i.e., almost 200 times higher, at the absence of complete break down) was exhibited by the aggregates collected from the soils Nos 3, 4 and 5. These considerable variations were mainly due to the differences in wetting, texture, such chemical properties as carbonate concentration and whether the examined soil was subjected to freezing processes or not. Furthermore, water resistance in individual soils was also affected, in various degrees, by the wetting compaction of the aggregates. Substantial dependencies were observed when considering the influence on DW of the sample compaction wetting and bulk density associated with it. For dry aggregates, it was easy to notice a significant improvement in their water resistance which reached its maximum at the point of the maximum sample compaction (Wsz) or at the point slightly above it. At higher wetting, DW dropped which can be contributed to considerable volume changes (swelling) of the shrunk aggregate during water intake. This dependence was most conspicuous for dry aggregates. In the case of wet aggregates, a slight shift of the maximum dynamic water resistance above Wsz was observed. When analysing wet frozen aggregates, a rapid drop of DW was noticeable at wettings higher than standard.

Variations in the dynamic water resistance in relation to the texture composition of the examined soil was found interesting. It can be said that the increase in the amount of colloidal fraction increases the value of dynamic water resistance to water action at all the examined measurement combinations. On the other hand, increasing humus concentration reduces the value of this parameter (e.g. soil No. 2).

At static water resistance, it was assumed that the maximum time for the measurement of disintegration would be 24 hours (86400 s). Long-term investigations [9] indicated unequivocally that majority of soils in Poland break up during this time. Only very few soils, primarily alluvial soils, soils of water origin (clays), as well as some black earths and chernozems do not undergo disintegration after this time. On the basis of investigations performed in this study, Rendzinas should also to be included in the above mentioned group. The examined soils – as in the case of dynamic water resistance – also exhibit considerable variations with regard to their resistance to the static water action. Results on the variability of aggregate static water resistance – expressed by their disintegration time – range from 8 seconds (soil No. 2, air dry aggregates) even up to 86400 seconds (the remaining soils, wet and wet-frozen aggregates). Both wet aggregates and those subjected to freezing/de-freezing processes are characterised by a very high static water resistance which indicates that, in the majority of cases, they do not undergo destruction even after 24 hours of wetting.

Summing up problems associated with dynamic and static water resistance of soil aggregates and their dependence on texture, soil wetting compaction and measurement of wetting as well as on the consequences of freezing processes, it should be stated that the evaluation of water resistance does not – by any means - determine the structure-forming role of the above mentioned factors. It appears that sometimes both dynamic and static water resistance of the primary aggregates ultimately lead to more favourable distribution of secondary aggregates. Secondary aggregation - which finds its expression in the quantity and quality of the secondary aggregates developed from the basic aggregate after it has been affected by the water factor – is a property which is essential for the understanding of dynamic changes of soil structures as well as for agricultural practice. It is this property that determines susceptibility of soil structures to positive and negative changes of basic physical soil properties, primarily by determining its state of porosity and density.

The analysis of the disintegration of the primary aggregates into secondary aggregates in the result of dynamic (Adw) and static (Asw) action of water was performed on the basis of the percentage content of secondary aggregates with dimensions exceeding 0.25 mm.

In the performed investigations, a distinct influence of colloidal fractions on both dynamic and static water resistance as well as the state of secondary aggregation can be noticed. The state of secondary aggregation after DW – taking into account sums of secondary aggregates bigger than 0.25 mm – remains at a relatively high level from several to over 90% of secondary aggregates, i.e. at the level considerably higher in comparison with other soils [9]. In the majority of cases, the highest totals of secondary aggregates, both after dynamic and static action of water, were obtained for wet aggregates subjected to freezing (Figs 2 and 3).

The most significant differences in the size and shape of secondary aggregates formed under the influence of dynamic and static action of water can be generalised as follows:

- Significant effect on the state of secondary aggregation (size of elements, process and degree of their disintegration) is exerted by: texture composition, wetting compaction and measurement, its compaction (density, porosity), the method water acts on the aggregate and, first and foremost, freezing processes.
- Diversified soil fraction composition - or more precisely, different concentration of fine, colloidal and silt fractions – exerts a very clear effect on the soil capability for secondary aggregation; with the increase of colloidal fraction, size and quantity of the secondary aggregates undergoes modification.
- The state of secondary aggregation (size and amount of aggregates) is significantly affected by the character of water action: dynamic or static.
- The process of disintegration of the primary aggregates into secondary ones varies depending on the moisture content at the time of measurement (wet or air dry aggregates). On the whole, the primary aggregates in air dry state exhibit a considerably lower capability for secondary aggregation, and this capability increases with the increase of colloidal fraction (higher cementing during the process of shrinking).
- However, the most significant effect on secondary aggregation was exerted by low temperatures; both freezing and de-freezing processes were found to be distinctly more intensive in wet aggregates and at higher compaction wettings.
- In comparison with other soils, a clear, sometimes distinct influence of humus and calcium carbonate on secondary aggregation in calcareous soils can be observed. Figures 2 and 3 exemplify the dependence of secondary aggregation on the percentage concentration of colloids, simultaneously, taking into account the concentration of organic matter. It is evident from the figures that large quantities of organic matter have a distinctly negative influence on secondary aggregation, while calcium carbonate – exerts a clearly positive effect. The degree of this influenc depends on the level of humus and calcium carbonate concentration.

CONCLUSIONS

1. Rendzinas selected for the investigations represent carbonate and gypsum rocks developed from rocks of various geological formations and this had a decisive

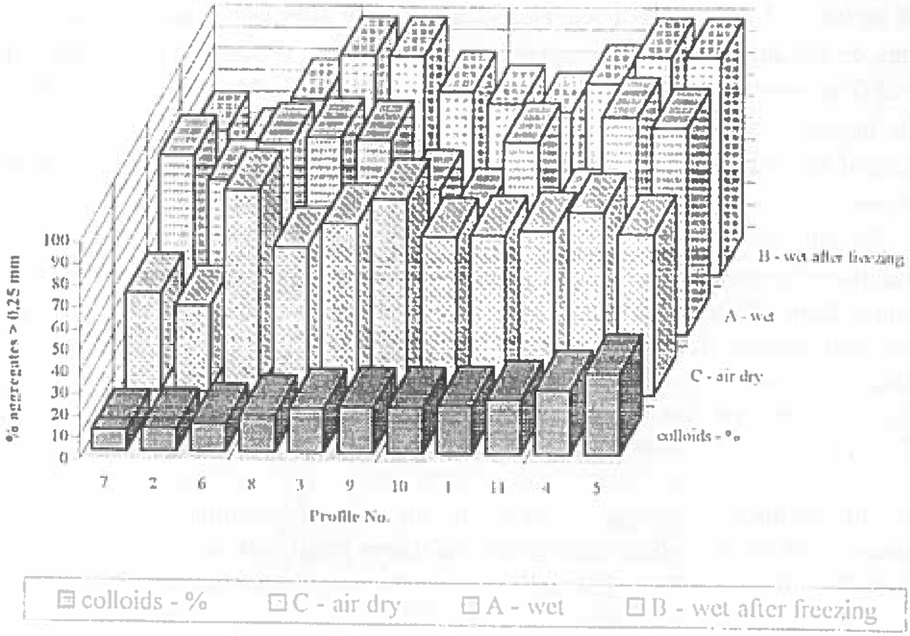

Fig. 2. Secondary aggregation after dynamic water action.

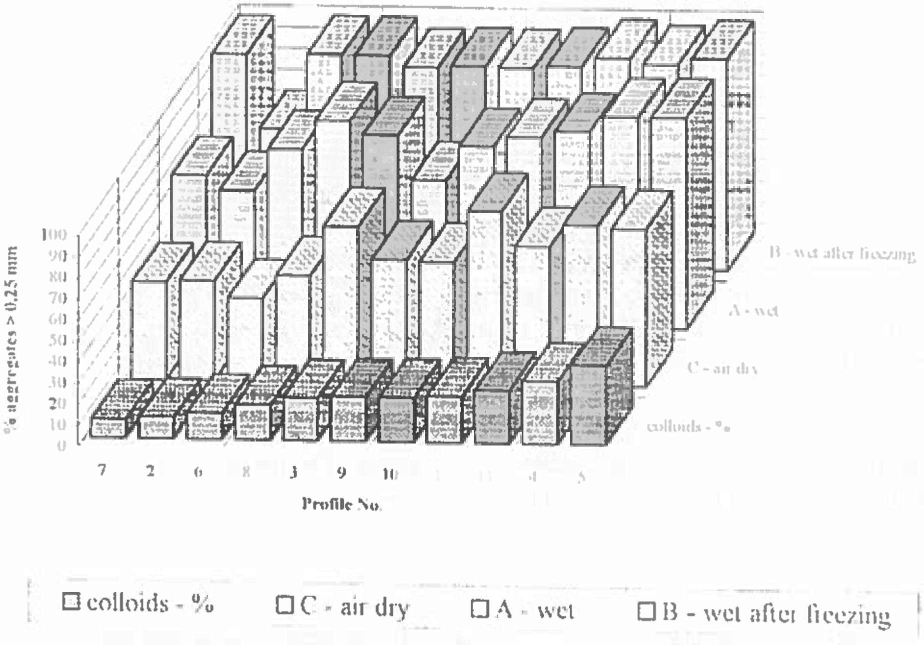

Fig. 3. Secondary aggregation after static water action.

influence on their basic physical and chemical properties, including their structure. A diversified resistance of parent rocks to weathering processes as well as an admixture of post-glacial materials made it necessary to identify these soils as different species.

2. In comparison with other soils, the state and structure-forming properties of Rendzinas, in particular water resistance of upper layers to static and dynamic action of water, is exceptionally high. On the basis of the results concerning aggregate structures it was found that the examined physico-mechanical parameters depended mainly on: texture composition, compaction and formation wetting of aggregates, their moisture content at the moment of taking measurements and porosity. Furthermore, a distinct, significant effect of freezing processes and, in individual cases, of the amount of organic matter and calcium carbonate on the analysed parameters was observed. The influence of the above mentioned factors on the examined physico-mechanical properties varied so much that in the majority of analysed samples the variation of these parameters was expressed in multiplicities of their values.

3. In conditions of temperate climate, freezing processes turned out to be an exceptionally important structure-forming factor. They exert a very favourable influence on the aggregate structure of the arable layer, in particular, on the state and stability of the secondary aggregates formed in the result of their action. Favourable secondary aggregation allows to preserve the developed aggregate structure in the sub-surface layer and to extend the period of relatively high soil porosity, hence of more appropriate air-water relations and of more suitable conditions for microbiological processes in soil. The effect of freezing processes increases with the increase of weight of soil texture composition.

4. Soil aggregates compacted in the laboratory in the way that imitates field conditions exhibit, in general, very similar physico-mechanical properties (formed according to the same principles) to aggregates of natural compaction and characterised by analogous wetting and porosity. However, modelled aggregates provide far greater possibilities for the analysis of structure-forming properties in varying, strictly controlled conditions of compaction, porosity and wetting of soil aggregates.

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