THIRD INTERNATIONAL WORKING-MEETING ON SOIL MICROMORPHOLOGY
WROCŁAW, 1969

ZESZYTY PROBLEMOWE POSTĘPÓW NAUK ROLNICZYCH 1972 z. 123

Microscopical investigations on soil aggregates

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INTRODUCTION

The soils show different aggregation in the humus accumulation horizon, depending on utilization kind, parental rock and soil climate. Soil aggregates differ from one another not only in qualitative, but also in quantitative respects. Structure-forming and destruction processes cause constant transformations of soil aggregates, i.e. their forming and disappearance. Therefore, soil aggregate formation will be different in humus accumulation horizons of particular soil types. Soil utilization is also of great importance for intensity of structure-forming factors influencing soil aggregation. Therefore, both quantity and quality of formed soil aggregates will be different in arable and orchard soil and in soil under grasslands and forests. Vershinin [22] distinguishes following factors of soil aggregate forming: climatic, pressure-hydrothermic, grass-root, coprolytic, agrotechnical and mixed ones. For each soil type there exist a definite arrangement of action and intensity of these factors, and simultaneously a specific aggregation degree in structure of arable soil layer. As is well-known, the soil aggregates are of very significant importance for agriculture, and in this connection the present investigations are aimed at their better recognition in respect of microstructure, under preservation of their undisturbed structure.

INVESTIGATION OBJECTS

The investigations involved soil aggregates of the humus accumulation horizon of acid brown soil utilized alternatively as meadow and pasture. The investigations were conducted on 6 isolated and separate aggregates of light and dark colour. This soil, developed from Carpathian Flysch rocks (clay shales, sandstones, limestones) is situated in mountains, at the Jaworki locality [8]. Its profile structure is: A_0—A_1—(B)—C. The humus horizon thickness is 0-28 cm, within the reach of the grass roots action. It is of grey colour, acid reaction, loose structure, mechanical composition of medium silty loam, with medium content of skeleton particles. According to the quantitative classification of J. Tokarski, this soil would belong to the series of clay-sandy soils and the loam group with following mineral composition: clay matter content (montmorillonite, kaolinite) — 17.4%, including 10% of kaolinite, 8.1% of organic matter, 0 carbonates, as well as 74.5% of sand (thermically inactive remainder).

INVESTIGATION METHODICS

1. Fractional composition of the aggregates was determined by passing soil samples through sieves with the mesh diameter: 6, 5, 4, 3, 2 and 1 mm.

2. Mechanical composition of soil sample taken from humus horizon was determined by the areometric Bouyoucos-Casagrande method in modification of Prószyński [14], and granulation of light- and dark coloured soil aggregates — under a polarizing microscope by the method of Tokarski [21].

3. Description of thin sections, mineral composition, structure elements, roundness degree of skeleton grains etc. were determined under microscope in polarized, parallel and convergent light [4, 5, 6] at magnification of 320×.

INVESTIGATION (DETERMINATION) RESULTS

In Table 1 the content of particular aggregate fractions, total and its division into dark- and light-coloured aggregates, is presented. There prevail coarse and fine aggregates, the least being medium-sized. Dark-coloured aggregates are more numerous than light ones. The colour differences are perceptible only in air-dry samples, and not in field conditions. Such differences in aggregate colour were found already in humus horizons of cultivated or forest brown soils and chernozems [20], which

Table 1. Fraction percentage of aggregates in humus accumulation horizon 0-28 cm

Fraction size, mm	Total fraction, %	Light-coloured aggregates, %	Dark-coloured aggregates %
Over 1	12.0	—	—
Under 1	34.1	—	—
0.5-1	—	45.50	55.50
1-2	10.3	10.00	90.00
2-3	4.6	38.00	62.00
3-4	3.4	29.58	70.42
4-5	3.0	39.48	60.52
5-6	7.6	36.43	63.57
Over 6	25.0	44.00	56.00

suggests an unequal organic matter distribution in soil of various sites. The organic matter decomposition runs at unequal rates and is not well mixed with mineral parts of the soil. Organic residues in soil occur in local agglomerations, constituting higher concentrations of decomposition products and giving unequal colour to soil crumbs.

The content of particular mechanical fractions is different (Table 2), but in the total content of sandy, silty and clay fractions only insignificant differences occur.

Table 2. Mechanical composition of humus accumulation, horizon 0-28 cm

Grain diameter, mm	Content in %
Over 1	12
1-0.5	7
0.5-0.25	13
0.25-0.10	17
0.10-0.05	12
0.05-0.02	16
0.02-0.006	14
0.006-0.002	17
Under 0.002	4
1-0.1	37
0.1-0.02	28
Under 0.02	35

MICROMORPHOLOGY OF THIN SECTIONS OF AGGREGATES

LIGHT-COLOURED AGGREGATES

In the fraction of 1-2 mm in dia extremely different skeleton grains — coarse and fine — are contained. In some of them fissures are visible. The cement (skeleton-binding substance) is of light or dark-brown colour (spotted) in the bulk of smaller nodules containing fragments of organic matter residues. These nodules are weakly bound with one another, constituting in their wholeness a conglomerate. The substance of plant residues is in most part at different decomposition and humification stages. In some aggregates organic matter occupies considerable space, occurring in form of condensed fragments or sometimes surrounding skeleton grains in form of an envelope of dark-brown colour. The pores appear as various tortuous channels or other irregular forms. The channels occur most often in such aggregate places, where the cement is less compact, or among coarse mineral skeleton grains.

The fraction of 2-3 mm in dia consists of coarse mineral grains of different form, unequally distributed, over the surface of which fissures and splintery planes are perceptible. Finer grains are sometimes condensated, with cement substance closely adhering them together. The cement is most often of brown-yellowish-rusty colour, more intense in the places of condensation. At nicols crossed, as a rule, isotropically, it consists usually of fine grains of "clouded" appearance. The plant residues consist of tiny fragments, partly decomposed, of different shape and size. A crumb consists of particular nodule-shaped elements, with irregular tortuous channels between them, widening or narrowing in certain places. Single pores, most often of lenticular shape, occur in various parts of the aggregate.

The fraction of 3-4 mm in dia has a diverse-grained mineral skeleton, unequally distributed. Coarse grains originate from rock fragments, sometimes fissured and splintery, covered on their periphery with dark-brown ferrugineous-humous substance. The cement is of dense and gelatineous consistency, of brown or dark-brown colour, heterogenous (spotted), often nodule-shaped, with plant residues at different decomposition stage. The pores appear as small channels and closed interstices, joined with one another by thin narrowings, occurring as oval or funnel-like forms.

The fraction of 4-5 mm in dia consists of coarse- and medium-sized grains condensed in some parts of the aggregates as well as of fragments of rocks and minerals. The cement is of brown-rusty colour, heterogeneous, nodule-shaped, with dark-brown or black fragments of organic residues. The whole crumb consists sometimes of such nodular segments. The channels run sometimes around coarse mineral grains bifurcating them and dividing the crumb into particular fragments. The channels are of different widths.

The fraction of 5-6 mm in dia consists of skeleton grains, constituting in some aggregates great rock fragments and in other ones fine grains. The grain is elongated, pillarshaped and sometimes fissured. The cement is of unequal brownish-rusty colour, appearing as a bulk of gelatineous nodules with fragments of plant residues of different size, at the initial decomposition stage. At the edge of some skeleton grains the cement bulk is distinctly condensated and of more intense colour, forming a characteristic envelope. The pores are of funnel-like shape, forming tortuous irregular channels, dividing some aggregates into nodular segments.

The fraction of over 6 mm in dia constitutes great and in single cases very great skeleton grains formed of weathered rock fragments, some of which are covered probably with a clayey-ferrugineous substance. The cement bulk is distinctly nodule-shaped and heterogenous, of rusty-brown or dark-brown colour. The plant residues are tiny and at different humification stages. Some fragments are rugged and show a vanishing cellular structure, unequal decomposition stages and variable colours. Pores appear as tortuous channels and closed oval forms.

DARK-COLOURED AGGREGATES

The fraction of 1-2 mm in dia consists of very coarse grains in singular arrangement as well as fine grains. Some mineral grains are strongly weathered and contaminated with weathered clayey material and organic matter. Some aggregates have coarse-grained and others fine-grained skeletons. The coarse skeleton grains in some parts of the aggregates lie closely next to one another and are surrounded by a condensed cement substance. The cement is of unequal brown or dark-brown colour, often with densely distributed elements of plant residues of brown or black colour, at different decomposition stages. The cement is partly isotropic (organic) and partly anisotropic (clayey); in some aggregates either is prevalent and adheres more closely to the edges of the mineral skeleton grains. The pores occur as short little channels or other closed forms.

The fraction of 2-3 mm in dia consists of fine and medium skeleton grains, sometimes condensated, fissured and contaminated with organic or humous-clayey matter. The cement is of light- or dark-brown colour (spotted), condensed and containing fine fragments of plant residues at different humification stages, closely adhering to the skeleton grain edges. In total bulk it forms small condensed gelatineous nodules. The pores occur as narrow and bifurcating little channels or other geometrical forms.

The fraction of 3-4 mm in dia consists of medium and fine skeleton grains, unequally distributed. Medium grains in some aggregates occur more often in form of agglomerations. Some of them are strongly weathered, fissured and contaminated with isotropic humus-clayey substance. The cement is of brown or dark-brown colour, almost fully isotropic and spotted in some places with tiny fragments of plant residues of dark-brown or black colour. Some of these fragments show a distinct cellular structure and are at different decomposition stages. The cement in its strongly decomposed part occurs in gelatineous, sometimes nodule-shaped form, of varied density. The pores occur as single narrow irregular little channels or closed interstices of small size and irregular shape.

The fraction of 4-5 mm in dia is composed of coarse grains originating from rock fragments and relatively lesser amounts of unequally distributed fine grains. Coarse grains are surrounded by an envelope of condensed cement, closely adhering to the grain edges. The cement is of irregular brown or dark-brown colour, almost fully isotropic, with fragments of plant residues. These fragments of black or rusty-brown colour are at initial decomposition stage; others are at advanced decomposition stage and show vanishing cellular structure traces. Strongly decomposed organic matter occurs as a gelatineous, very fine-grained substance, sometimes covering the mineral skeleton grains or forming nodule-shaped elements of different consistencies connected with decomposition processes during soil crumb formation. The pores occur as single closed interstices of various geometrical shape and tortuous narrow little channels, differently distributed in the crumb.

The fraction of 5-6 mm in dia is composed of irregularly distributed medium-sized mineral grains, among which sometimes coarse grains are to be found. Some mineral grains are covered with isotropic substances of dark-brown colour. The cement is of brown or dark-brown colour, condensed, forming irregular small nodules consisting of very fine grains and balls. The plant residues, irregularly distributed, of black or brownish-black colour, sometimes show cellular structure traces. The pores occur as closed or capillary interstices of different shape, arranged singularly or in connection with one another, creating a characteristic pore system in crumbs.

The fraction of over 6 mm in dia consists of coarse and medium mineral skeleton grains occurring in certain aggglomerations in some aggregates. Particularly large grains constitute rock and mineral fragments, with perceptible fissures and contaminated with isotropic weathered material. The cement is of dark-brown colour, condensed, nodule-shaped, fine-grained, heterogenous, and mostly isotropic. The plant residues are of large size and of black or brownish colour, some of them showing a vanishing cellular structure. The cement adheres strongly to the mineral skeleton grains, forming a distinct envelope. The pores constitute wide or narrow and short, tortuous and sometimes closed channels, bifurcating here and there inside the crumb and creating a pore system similar to a "neuron".

GRANULATION OF LIGHT- AND DARK-COLOURED AGGREGATES

The granulation of the mineral skeleton of aggregates is presented in graphs (Figs. 1, 2, 3, 4, 5 and 6) in the form of summation curves. These curves distinctly illustrate different diameter magnitudes in particular light- and dark-coloured aggregates. Coarse grains comprise the fractions of dark-coloured aggregates of 6-5, 4-3 and 3-2 mm, and those of light-coloured ones of over 6 mm in dia. The fractions of 5-4 and 2-1 mm in dia behave differently: the fraction of 5-4 mm of dark-coloured aggregates consists of coarse grains up to 75 μ and coarser grains over this size are in light-coloured aggregates; the fraction of 2-1 mm of light-coloured aggregates consists of more amounts of coarser grains, up to 35 μ than in dark-coloured ones, of more amounts of grains up to 83 μ in dark-coloured aggregates than in light-coloured ones, and of greater amounts of coarser grains over this size in light-coloured aggregates than in dark-coloured ones.

PRINCIPLE MICROSTRUCTURE ELEMENTS OF LIGHT- AND DARK-COLOURED AGGREGATES

In considering the structure of light- and dark-coloured soil aggregates three main elements have been distinguished: (1) skeleton, represented mainly by detritus minerals, rock fragments and very weakly decomposed organic plant residues; (2) cement, substance binding skeleton grains, composed of clayey minerals and organic matter; (3) porosity, interstices

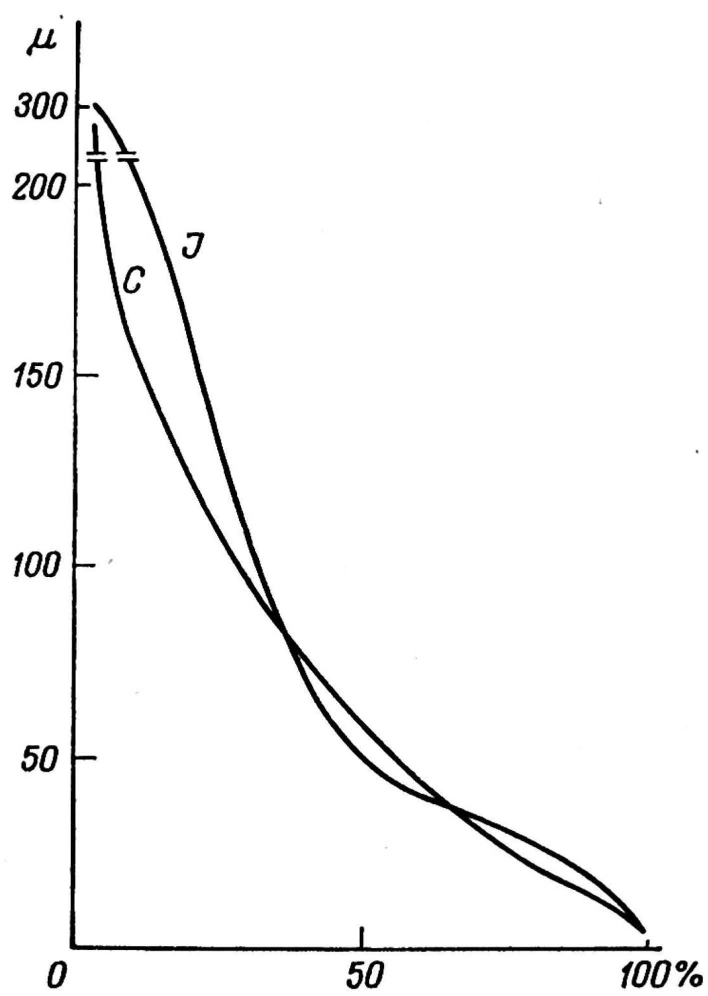

Fig. 1. The granulation of light and dark aggregates. Fraction of 2-1 mm diameter, summation curves.

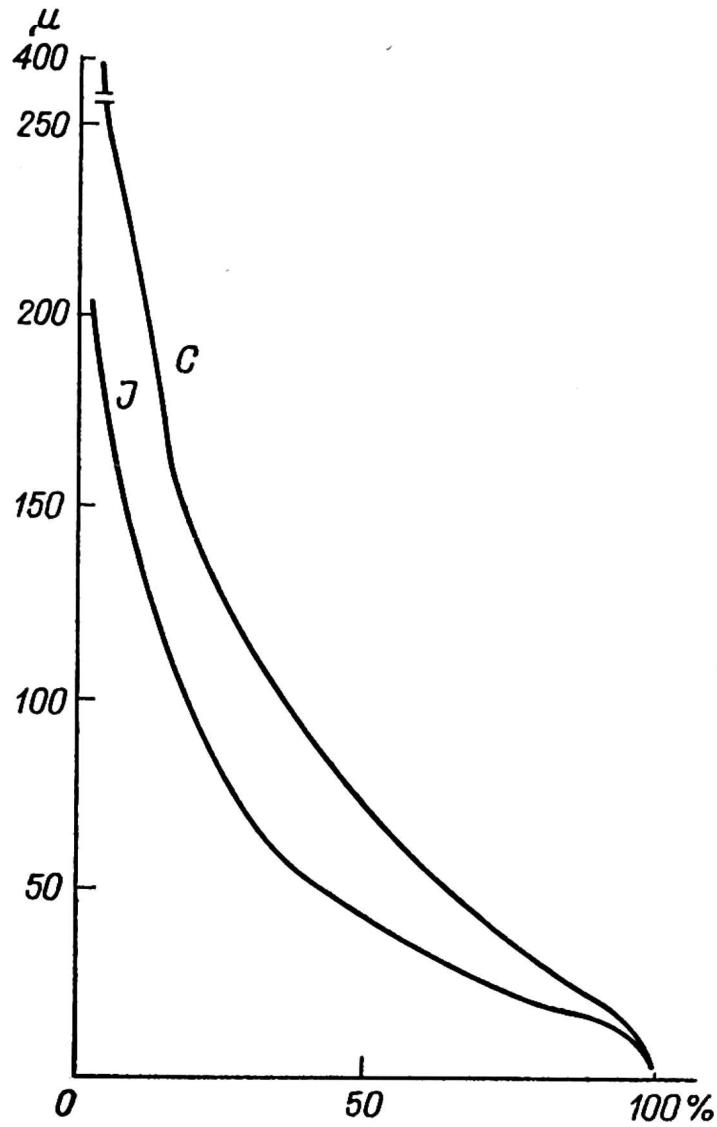

Fig. 2. The granulation of light and dark aggregates. Fraction of 3-2 mm diameter, summation curves.

of capillary channels and closed pores of different shape and size. Mineral detritus content is slightly higher in light-coloured aggregates than in dark-coloured ones, except in the fraction of 3-4 mm in dia. The content of binding substance (cement) is higher in light-coloured than in dark-coloured aggregates, except in the fractions of 3-4 and 2-1 mm in dia. Porosity is greater in dark-coloured aggregates than in light-coloured ones, except in the fractions of 3-4 and 2-1 mm in dia. The porosity is more diversified with regard to geometrical forms in dark-coloured than in light-coloured aggregates.

MINERAL COMPOSITION OF THE DETRITUS SKELETON OF AGGREGATES

The skeleton and its form play a very significant role in stability and waterproofness of the aggregates [18, 19]. To these features particular attention was paid by Antipov-Karatayev *et al.* [2] and by Tokaj [18, 19]. In the investigations on skeleton features 5-degree roundness scale after Rukhin [17] was used. The conducted determinations, numerical values of which are put together in Table 3, have proved that in the skeleton, sharp-edged, angular and weakly rounded grains are contained whereas

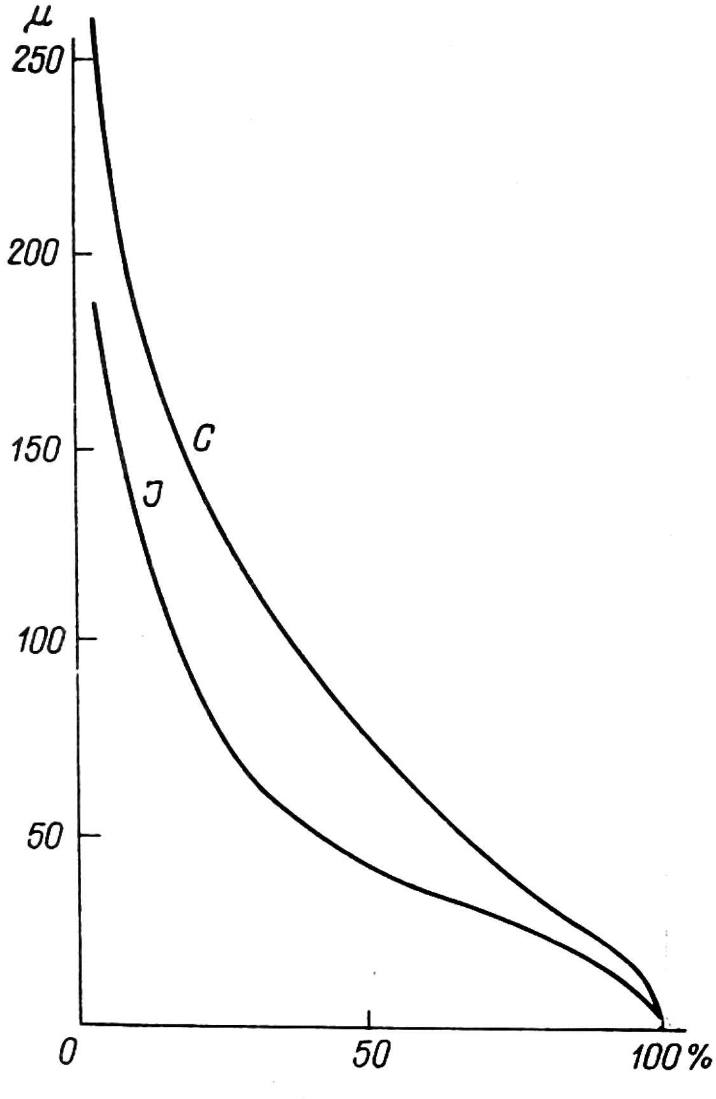

Fig. 3. The granulation of light and dark aggregates. Fraction of 4-3 mm diameter, summation curves.

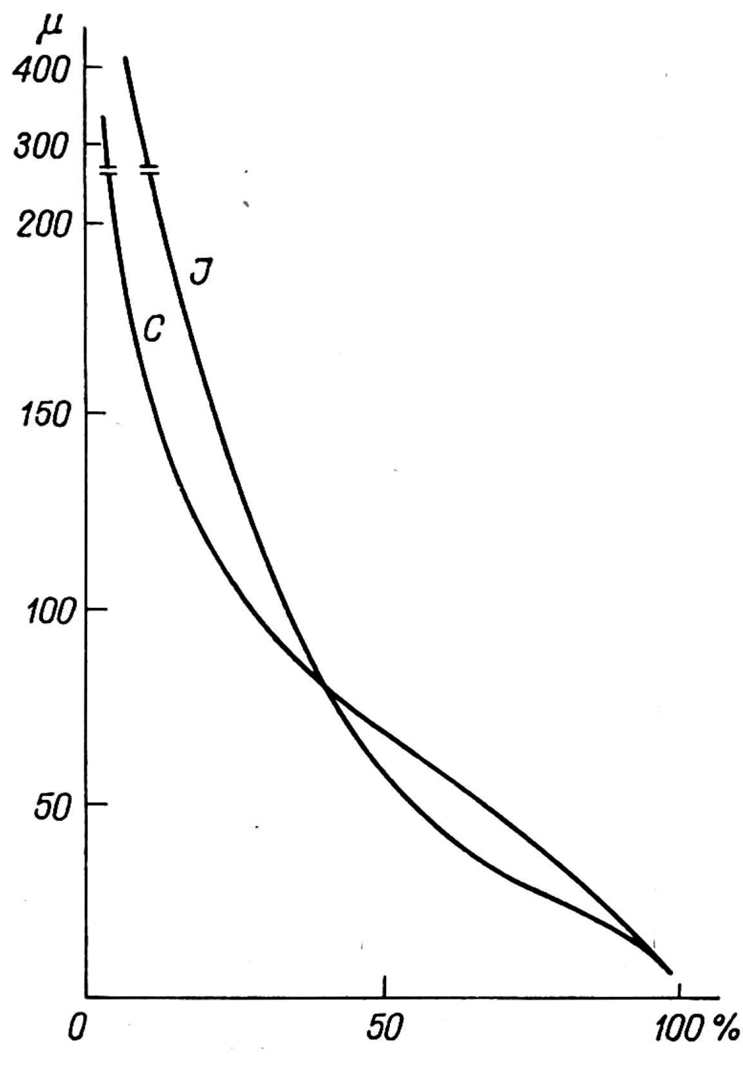

Fig. 4. The granulation of light and dark aggregates. Fraction of 5-4 mm diameter, summation curves.

non-rounded or well-rounded grains were found. More sharp-edged and angular grains contain more dark-coloured than light-coloured aggregates. The binding substance adheres more strongly to the sharp-edged and angular grains and better binds the skeleton of the aggregates, increasing their waterproofness and compactness which is of particular importance during the destruction processes of soil aggregates. A medium degree of roundness in the mineral skeleton in less prevalent in dark-coloured than in light-coloured aggregates.

DEGREE OF ROUNDNESS OF MINERAL SKELETON OF AGGREGATES

The mineral skeleton of the aggregates consists of rock and mineral fragments and of very weakly decomposed organic plant residues. Skeleton particles, both inorganic and organic, influence the quality of soil aggregates and their chemico-biological dynamics. Mineral composition of the skeleton is presented in Table 3, without organic matter consideration. The determined minerals presented in the table can be divided into two main groups: (1) — "barren" (passive) mineral group — quartz, chalcedony, sandstone and quartzite fragments; (2) — group of "active" minerals: felspars, muscovite and organic substance containing nutrients temporarily unavailable to plants, such as K, Ca, Mg, Fe and N. Generally it can be stated that light-coloured aggregates contain more "barren" group elements than dark-coloured ones, while the latter contain more elements of the second group, i.e. are potentially more abundant in the above nutrients.

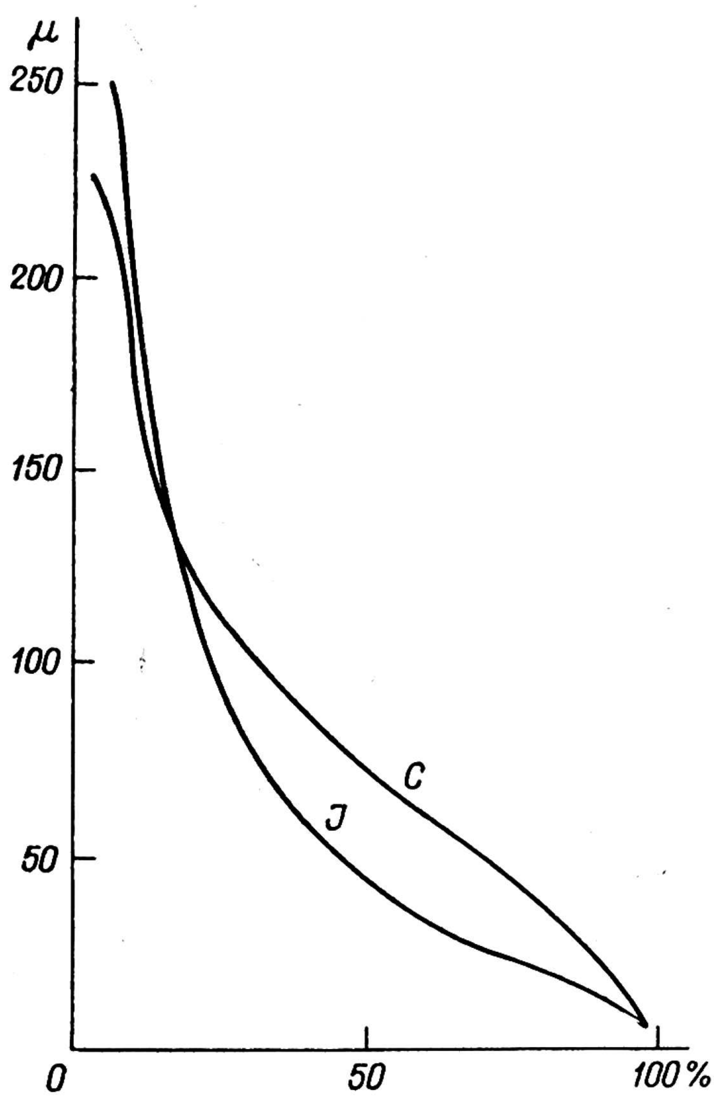

Fig. 5. The granulation of light and dark aggregates. Fraction of 6-5 mm diameter, summation curves.

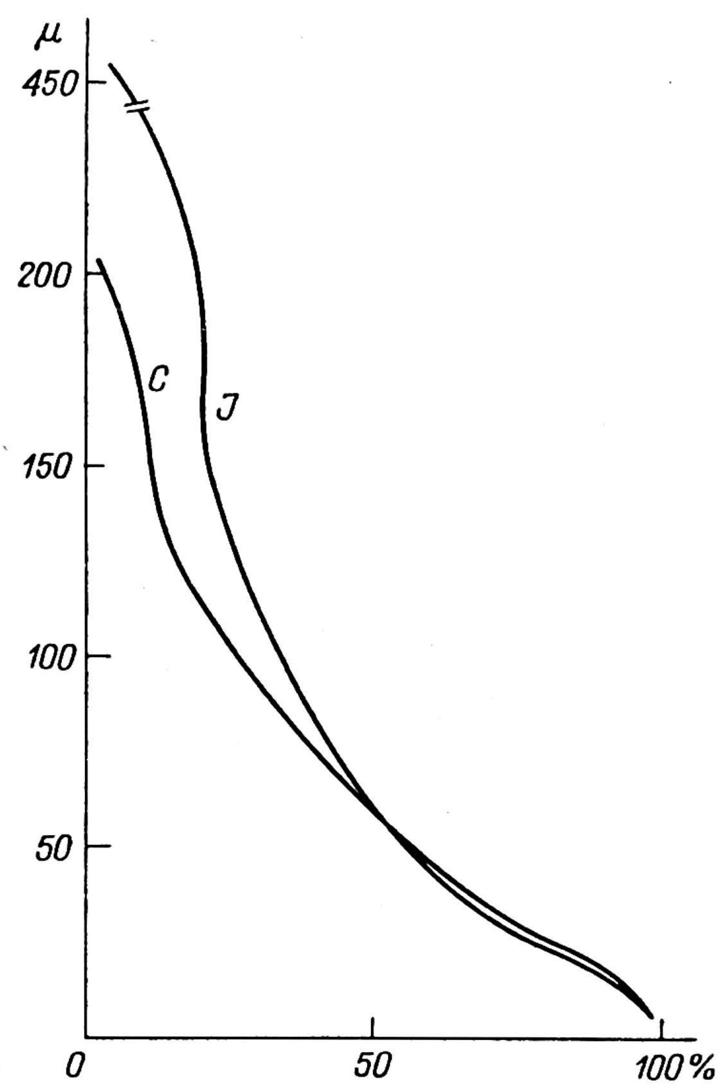

Fig. 6. The granulation of light and dark aggregates. Fraction of 6 mm diameter, summation curves.

Table 3. Microstructure and mineral composition of soil aggregates in humus accumulation, horizon 0-28 cm

Fraction, mm	Colour of aggregates	Mineral detritus of skeleton, %	Binding substance (cement), %	Porosity, %	Pore size, μ	Quartz, %	Chalcedony, %	Sandstone of quartzite, %	Orthoclasse, %	Plagiovite, %	Muscovite, %	Other[a], %	Sum of col. 7, 8, 9, %	Sum of col. 10, 11, 12, %
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1-2	light	33.7	54.3	12.0	37.5-262.5	65.0	0.0	23.3	6.7	3.3	0.7	1.0	68.3	30.7
2-3	,,	36.0	56.0	8.0	37.5-225.0	41.0	9.0	3.7	29.7	2.0	14.6	0.0	53.7	46.3
3-4	,,	27.3	62.7	10.0	37.5-187.5	70.7	6.0	0.0	14.7	1.3	3.3	4.0	76.7	19.3
4-5	,,	33.0	63.0	4.0	37.5- 73.0	73.4	2.7	0.0	17.0	0.3	4.3	2.3	76.1	21.6
5-6	,,	20.0	75.3	4.7	37.5-112.5	57.3	2.0	0.0	24.0	0.7	3.7	12.3	59.3	28.4
6	,,	30.0	63.3	6.7	37.5-150.0	60.0	1.3	3.7	16.0	1.3	2.7	10.0	65.0	20.0
1-2	dark	30.0	62.7	7.3	37.5-150.0	55.7	4.0	0.0	26.3	3.0	9.0	2.0	59.7	38.3
2-3	,,	36.7	55.5	9.0	37.5-112.5	70.7	4.0	0.0	13.0	2.3	6.0	4.0	74.4	21.3
3-4	,,	27.0	68.0	5.0	37.5- 75.0	64.3	4.7	0.0	16.7	1.3	8,0	5.0	69.0	26.0
4-5	,,	47.0	49.3	3.7	37.5-112.5	62.3	3.7	0.0	19.3	2.7	10.3	1.7	66.0	32.3
5-6	,,	17.7	74.0	8.3	37.5-187.5	54.0	4.0	1.4	28.3	5.3	5.0	2.0	59.4	38.6
6	,,	28.0	54.3	17.7	37.5-225.0	68.0	8.7	3.0	14.7	1.0	6.6	3.0	79.7	22.3

[a] Mineral isotropic of strongly weathered and contaminated with weathered material or organic matter.

Table 4. Roundness degree of mineral skeleton grains

Fraction mm	Colour of aggregates	Grain kind				
		sharp-edged, %	angular %	weakly rounded %	medium rounded, %	sum of sharp-edged and angular grains %
1-2	light	76.75	7.25	16.0	23.25	84.0
2-3	,,	75.50	9.25	15.5	24.75	84.75
3-4	,,	74.00	9.0	17.0	26.0	83.0
4-5	,,	75.76	9.75	13.5	23.25	85.51
5-6	,,	77.5	8.0	14.5	22.5	85.5
6	,,	78.2	8.0	13.5	21.5	86.2
1-2	dark	81.25	8.25	10.5	18.75	89.5
2-3	,,	88.5	8.0	13.5	21.5	86.5
3-4	,,	80.5	7.0	12.5	19.5	87.5
4-5	,,	80.75	8.75	10.5	19.25	89.5
5-6	,,	77.25	7.25	15.5	22.75	84.5
6	,,	79.25	9.25	11.5	20.75	88.5

DISCUSSION OF THE RESULTS AND CONCLUSIONS

The conducted microscopic investigations of soil aggregates of the humus accumulation horizon have shown distinct differences both of micromorphological and micromorphometrical features of aggregates of light and dark colour. In the domain of soil micromorphology the investigations of Kubiëna [11-13], Kowaliński [9, 10], Altemüller [1], Kubiëna, Beckmann and Geÿger [13], Polskiy [16], Jabłoński [7], Parfenova and Yarilova [15] and others deserve particular attention. On the other hand, there are very few works in the literature on the micromorphological and micromorphometrical features of the soil aggregates as such. The hitherto results of investigations on the above features allow to state that the microstructure of light- and dark coloured aggregates is not the same in the humus accumulation horizon of particular soil types [20] and at different utilization kinds. The physical and chemical properties of soil depend on the quality of the aggregates and on the mutual relation between the particular fractions. The influence of structure-forming factors on the processes of soil material aggregation differs not only in the given soil type, but also in the genetic horizon. Porosity is a very important aggregate structure element, since it influences water and air (oxygen) circulation in soil crumbs, and consequently the biological activity and agricultural value of the soil. Therefore, much attention is paid to the investigations on soil porosity in polished sections [1, 16] and thin sections [3, 9, 10, 20]. Beckmann and Geÿger [3] worked on the project of pore classification in soil, distinguishing fissures (cracks) formed in drying soil and other free spaces of various forms.

Among other things the method of soil utilization kind, soil climate and microorganisms play a significant role, in the course of particular soil-forming processes influencing formation of the aggregates of light and dark colour. The quality of soil microorganisms and physical conditions influence the decomposition rate of organic matter, of dead root residues [7] in humus horizons. The decomposition products forming under the influence of geochemical processes of water circulation in soil cause a colour differentiation of soil aggregates in the places of contact of organic matter with mineral inorganic material. To the organic matter humification process in soil, cultivated and under sod, as well as to soil colour, particular attention is paid by Kowaliński [10]. The method of utilization of soil and specific soil climate in humus accumulation horizon within the grass root system reach leading in growing season to phase-dynamical decomposition of the died root residues, and in this connection to formation of lesser or greater amounts of decomposition products of different concentration with water circulating in the soil. The water of different concentration filtrating and circulation in the given horizon causes varied degrees of saturation of soil aggregates after or during their formation, and thus their different colour. Microscopical analysis of thin sections and chemical analysis [20] have proved that in dark-coloured, aggregates higher amounts of organic matter substance are contained than in light-coloured ones, even though they occur at different decomposition stages. It is to be stressed that in the dark-coloured aggregates higher amounts of iron hydroxides are contained [20], which, together with organic matter decomposition products, determine the colour intensity. Coarser, sharp-edged grains, with a lesser degree of roundness make organic matter (residues of plant roots) adhere stronger such grains in the formation process of a soil aggregate, and there in its less distinctly different structure as well as chemical and physical properties [18, 20]. Also, the fact deserves attention that a higher content of active minerals in the skeleton, as well as porosity create undoubtedly better conditions for development of soil microorganisms (bacteria, fungi) in dark-coloured aggregates than in light-coloured ones. Owing to the above features, the dark-coloured aggregates are of higher agricultural value than the light-coloured.

CONCLUSIONS

The conducted microscopic investigations on soil aggregates of the humus horizon of acid brown soil under grassland lead to following conclusions:

1. The separated and isolated fractions of light- and dark-coloured aggregates differ from one another with respect to micromorphology and main microstructure elements. The differences between dark- and light-

coloured aggregates are greater than those between aggregates of particular fractions.

2. The mineral composition of dark and light aggregates is different, too. Light-coloured aggregates contain more elements of the so-called "barren" group: quartz, chalcedony, sandstone, quartzite, while dark-coloured ones — more "active" minerals contain some potential nutrients (K, Ca, Mg) as well as felspars and muscovite. Undecomposed plant residues constitute an organic skeleton.

3. Average of degree roundness in mineral skeleton grains is less in dark than in light aggregates. Dark aggregates contain more sharp-edged and less weakly-rounded grains and more coarse grains than light ones.

4. Total content of cement (skeleton-binding substance) is less in light-coloured, than in dark-coloured aggregates. These differences are both qualitative and quantitative. Dark aggregates contain more organic matter and minerals of montmorillonite group than light aggregates.

5. Dark-coloured aggregates show in majority of the fractions investigated quantitatively greater porosity and qualitatively greater diversity of geometrical forms than light aggregates.

6. Examination of thin sections of soil aggregates under a polarizing microscope delivered many valuable informations about the nature and properties of soil aggregates and their estimation from an agricultural value point of view.

SUMMARY

The author intended to determine the micromorphological and micromorphometrical properties of the soil aggregates as structure-forming and agriculturally valuable elements of the soil. The investigations comprised aggregates, light- and dark-coloured, extracted from an air-dry soil with the help of a specially prepared "natural colorimeter". The following fractions of crumbs were examined: diameters of more than 6 mm, of 6-5, 5-4, 4-3, 3-2, and 2-1; they were taken from an acid brown meadow soil formed on rocks of the Carpathian Flysch. The mineral composition and properties of light and dark aggregates are different. The differences between light and dark aggregates are greater than those between uni-coloured aggregates of separate fractions.

The examination under the polarizing microscope of thin sections made from soil aggregates, supplies much valuable information on their nature and properties for the estimation of their agricultural value.

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