INFLUENCE OF SOIL DRYING ON THE FORMATION OF STRUCTURAL ELEMENTS IN GRAY FOREST SOILS

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Peculiar features for the formation of structural elements (clasters) and regularities in their growth have been identified by precipitating the clay fractions extracted from samples of gray forest soils in water suspensions with the view of determining the mechanism responsible for the formation of the soil microstructure under the influence of temporary wetting-drying processes. Under use were suspensions of soil samples (<1 mkm) prepared by traditional methods for the particle-size distribution and microaggregate analyses and preliminary dried (1-2 times). One suspension drop taken by a pipette from the middle part of the test-tube was placed on the laboratory glass of 1x1 cm size. After the water evaporation (48 hours) this procedure was repeated once more and 14 samples were prepared including 7 samples with the clay precipitation from one suspension drop and 7 samples from two suspension drops. Then the raster electronic microscope REMJEOL 6060A was used for scanning of these preparations. The mathematical processing permitted to identify tend towards increasing the accumulation of fine-sized particles, its quantity and decreasing the distance between the formed clasters in the course of their precipitation. When developing clasters of the second order (cyclic precipitation) it seemed possible to establish that the distribution density of structural elements is sharply increased and newly formed clasters can lead to irreversible changes in the soil microstructure and the aggregate destruction. Only the humus promotes weakening these processes. In samples of parent materials such changes in the size of claster doesn't occur under identical conditions.

Keywords: claster, particle-size distribution, microaggregate analysis, fractal analysis, dispersion coefficient.

INTRODUCTION

Processes related to the soil structure formation at a microlevel are described by using parameters of dispersion and heterogeneity, the latter being conditioned by the presence of surfaces formed between the phases in soils. The up-to-date investigation methods permitted to establish that these inter-phase surfaces reveal structural elements in the kind of clasters – fine soil particles averaged to 40 nm in size and represented predominantly by accumulation of flat anisometric clay minerals. With increasing the dispersion and decreasing the size of soil particles in the liquid phase the role of structural elements (clasters) becomes significant in the process of coagulation – consolidation, adhesion of the most coarse soil particles. The fact is that due to decreasing the size of soil particles their other characteristics can assume ever greater importance including the fractality and as a consequence the ability to form surfaces which are similar to each other. Spatial networks of structural elements in soil occur at the expense of fine fractions (≤ 1 mkm), capable to take part in heat Brown movement. Just it serves as a condition for soil particles to lose their aggregate stability (stability to coagulation), being accumulated to the critical level in the liquid phase; they become resistant to precipitation and the time requiring for this process gets slower. The aggregate strength is considered as an indicator for critical concentration of soil particles because it is changing with increasing the number of contacts between the particles in dependence on their form and size. The contact interactions of soil particles at the surface between the phases play a significant role [5].

This paper is aimed to study the formation of structural elements (clasters) in the course of precipitating the fine-dispersed particles in water suspensions with the view of determining the mechanism responsible for the formation of the microstructure under the influence of periodical wetting-drying processes.

INVESTIGATION METHODS

Model experiment. The objects of model experiment were soil samples taken in horizons of the gray forest loamy soil on mantle loess-like loams in the south of the Moscow region (pit 1) as well as the samples from the BTC horizon in pit 4 located on a gentle slope elevated by 140 m [2]. The samples were taken at a depth of 60–110 cm in the lower part of the slope. The soils occupy an area under crops.

Pit 1 is located under the thin pine forest with well developed undergrowth of broad-leaved woods and shrubs. Relief is a gently sloping watershed area elevated by 180 m. Microrelief is indistinct. The natural type of the profile is AO (0–4 cm) – AY (4–15 cm) – AEL (15–28 cm) – BEL (28–45 cm) – BT1 (45–65 cm) – BT2 (65–105 cm) – BTC (105–130 cm).

The soil samples were taken at a different depth and their preparation for laboratory test included air-drying and sieving through 1 mm sieve. The particle size distribution was determined using sodium pyrophosphate and ultrasound effects (Kachinskiy's modification method). The microaggregate composition was detected after Kachinskiy and the swelling parameters – after Vasiliev method. The experiment scheme included two stages of preparing the soil samples for laboratory analyses. The first stage included standard preparation of soil samples, their wetting to the total moisture capacity by capillary saturation, drying at 105ºC, grinding and sieving through 1 mm sieve. The second stage – the same procedures in double replication. Analyses were performed in the laboratory of the V.V. Dokuchaev Soil Science Institute.

One drop of the prepared suspension (<1 mkm or 25 ml) was taken by pipette after its shaking to the complete dissolution and placed on a laboratory glass (1x1 cm). After 48 hours of water evaporation this procedure was repeated. Thus, 7 glasses with clay precipitation obtained from one drop and 7 glasses – from two drops were prepared for this experiment.

Technological cycle of the image analysis by raster electronic microscope included soil sampling and preparing the samples for REM scanning, 3D reconstruction of obtained images and mathematical processing - statistic methods and parameter calculation of fractal geometry. JEOL 6060A was used for these purposes. The algorithm including AdobePhotoshop program, RGB regime of images, mathematical processing by "Collector 1.5.1" program [8] allowed obtaining the necessary information on parameters of the heterogeneous surface structure, the complicated pattern of which is difficult to describe [3].

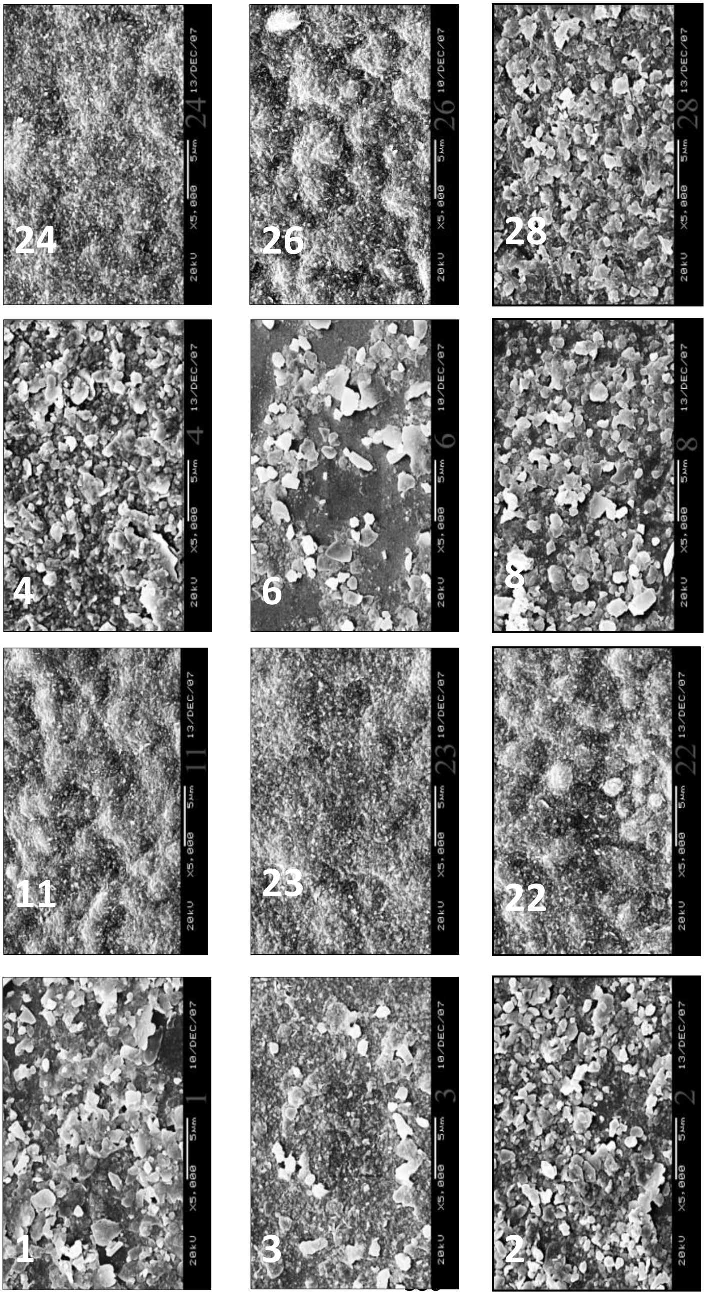
Such structures can be studied by means of fractal geometry [4]. The fractal dimension

looks like $d = \log N / \log 1/r$,

where N – a number of the studied objects; r – the similarity coefficient. This dimension is one of the main characteristics of the fractal system and permits to analyze in detail the properties of a great number of the studied objects. "Fractan" program permitted to calculate the fractal dimension determining the Herst index (*H*) connected with the fractal dimension (d) by $d = 2 - H$ ratio in 2D measurement. To characterize quantitatively the fractal properties of the studied soil samples, digital processing of REM images made it possible to identify the heterogeneity of the soil structure. Changes in the image brightness (white and black color) were proportional to the curve inclination for every surface structure.

Table 1. Objects of model experiment prepared for electronic microscopy

No. image	Pit, horizon	Depth, cm	Water suspension of the silt fraction					
			particle size distribution					microaggregate analysis
			sample after single drying				sample after double drying	sample after single drying
			amount of suspension drops					
			1	2	1	2	1	2
1	1,AY	10–15	+					
4	1,AY	10–15			+			
11	1,AY	10–15		+				
24	1,AY	10–15				+		
2	1,AEL	20–25	+					
22	1,AEL	20–25		+				
3	1,BTC	120–130	+					
6	1,BTC	120–130			+			
23	1,BTC	120–130		+				
26	1,BTC	120–130				+		
8	4,BTC	90–110					+	
28	4,BTC	90–110						+
10	4,BTC	90–110	+					
30	4,BTC	90-110		+				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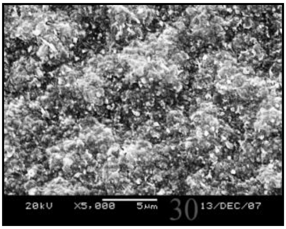

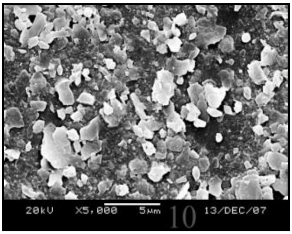

Fig. 1. Electronic images of surfaces of silt particles precipitated in water suspensions (numbering is given in Table 1).

RESULTS AND DISCUSSION

The soils developed on mantle loams and confined to sandy terraces of the Oka stream reveal instability to changes in the content of different granulometric fractions caused by periodical wetting and drying processes up to the absolute dried state [1]. The light-textured soil-forming rocks have a great amount of sandy fractions and the soil mass is more friable in consistence.

In dependence on moisture conditions in relief positions the total content of clay fractions in soil is lower by 1.5–2.0 times as compared to that located in elevated watershed areas in some distance from the Oka valley, where their content makes up 30% and the amount of sandy fractions is increased by 1.2–1.7 (pit 4).

The structural transformation of dispersed systems at a stage of diagenesis is conditioned by processes of compaction and dehydratation [7]. These processes are connected with a number of coagulated contacts between soil particles. The microaggregate composition allows characterizing a number of such contacts and adhesion of soil particles. It makes also possible to assess the ability or inability of the studied soil to spontaneous regeneration of the structure.

The periodical wetting-drying processes of the dispersed phase in the gray forest soil (in the range from the total moisture capacity to the absolute dry state) should be considered as a model of changes in morphometric and energetic features of the microstructure inherited from the underlying bedrock.

The soil with a stable structural organization is characteristic of changes in aggregation (coagulation) of soil particles. These changes occur slowly especially in humus horizons, in which the contacts between phases are well developed [6]. The soil-forming rocks are also subjected to coagulation-induced transformation however the conditions and time required for sedimentation have an influence on possible changes in dispersion when the soil is dry. The coagulation strength of soil particles becomes increased with increasing a number of drying periods. The common trend is the formation of a homogenous microstructure in soil characterizing by maximum compaction, low porosity and dehydratation. An intermediate product is the rock with skeletal or laminar microstructure and the final product – the sedimentary rock. Under conditions of agrotechnogenesis these processes become more intensive in watershed areas with the prolonged period of soil drying. The density of soil-forming rocks is always higher than that in upper soil horizons. The gravity compaction serves as a cause for transforming the primary precipitation of silt grains covered by clayey films with a friable skeletal microstructure into a compacted homogeneous structure without large micropores. The microstructure of upper soil horizons is determined not only by an organogenic component but also by cyclic periods of drying-wetting processes. The intensity of changes in the dispersion and microaggregate composition of gray forest soils is quite different in the course of the above processes: the dispersion of the soil mass is changed more slowly as compared to compaction of soil particles, changes in the dispersion are determined by a number of microaggregates. Such changes in the structure formation are connected with peculiar features of fractal structural elements (clasters) in the dispersed system.

With the view of determining this dependence the digital morphometric processing of REM images permitted to study precipitation surfaces of silt particles in water suspensions prepared from samples of the gray forest soil (Table 2). In the upper humus horizon containing a great amount of microaggregates the projecting cover of the surface made up more than 43%. The concentration of silt fractions in the BTC horizon reached 30% where the most large and compact particles form fractal clasters rounded by the other particles, that is why the area of projecting cover gets declined to 34%.

The soil samples affected by double wetting and drying revealed the formation of clasters conditioned by particle aggregation degree.

Table 2. Morphometric parameters of REM images

No. image	*N*	*S*	*P*	*d*	*L*	Ku	*H*
		mkm					
1	229	5667	412.7	85.0	90.9	0.07	0.73
2	273	4258	345.7	73.6	76.5	0.04	0.44
3	561	1977	201.5	50.2	59.6	0.18	0.64
4	382	2856	271.3	60.3	69.5	0.15	0.67
6	220	5077	359.6	80.4	99.7	0.24	0.55
8	310	3886	319.8	70.4	71.0	0.01	0.38
10	283	3898	286.6	70.5	71.5	0.01	0.46
11	443	2534	235.0	56.8	71.6	0.26	0.45
22	445	2551	240.9	57.0	68.4	0.20	0.60
23	580	1772	206.1	47.5	68.1	0.43	0.47
24	636	1683	195.4	46.3	64.2	0.38	0.71
26	473	2704	240.7	58.7	67.7	0.15	0.56
28	384	3021	286.7	62.0	64.3	0.04	0.51
30	421	2839	272.1	60.1	69.7	0.16	0.47

Note: *N* – a number of structural elements; *S* – average area of structural elements; *P*– average perimeter of structural elements; *d* – average diameter of a structural element; *L* – average distance between central parts of adjacent structural elements; Ku– packing coefficient of structural elements; *H* – Herst coefficient.

Due to destroying of particles in the upper soil horizons the amount of structural elements in silt fractions is quickly increased in the range from 400 to 600 and the form of these formations becomes acute-picked. The secondary clasters are capable not only to destruct the primary ones but also to remain unchanged, thus depositing on them or filling up the periphery.

The initial samples have a trend to leveling of the contact layer at the expense of a new material in periphery, increase in size of a newly formed structural element and decline in its variability to 40%. The old aggregate formations are destroyed being transformed into newly formed ones. The clasters assume a convex form with flat pick.

In the experiment variant with the repeated precipitation of clay particles at the surface formed by these particles under initial conditions an average size of new clasters (46 mkm) becomes sharply decreased in the humus horizon and characterized by flat-picked form. In such a complicated picture the structure can be assessed only by packing coefficient (Ku). The packing coefficient is a ratio of the distance projection between clasters to their diameter:

$$Ku = (L - d)/d,$$

where L – a distance projection between central parts of adjacent clasters, d-an average size of the structural element ($d = \sqrt{S}$, nm).

The packing coefficient, the maximum of which approximates to 0.4 was calculated using the data of morphometric parameters for REM images in 2D measurement. It is affected not only by the amount but also the size of structural elements: the larger are clasters in size, the lower is their amount requiring for packing. The calculations showed that at the first stage of experiment the packing increases with declining the size and distance between clasters but their amount becomes increased simultaneously. At the second stage of experiment with the repeated precipitation of soil particles (two drops of suspension) the packing coefficient shows the increase to 0.26 in the upper horizon and 0.43 in the BTC horizon. With increasing the amount of clasters their size gets decreased.

When clasters of the second order are formed, the density of structural elements distribution becomes increased and new clasters are formed close to the surface in the field of maximal concentration of the precipitated soil particles. In this case the silt particles reveal an uneven distribution with depth and assume a bimodal character being highly concentrated close to the surface. In the experiment variant with precipitation of soil particles subjected to repeated drying the formed structure becomes significantly dense due to increasing the amount of clasters and decreasing their size in the humus horizon, whereas the amount of structural elements averaged in size is insignificantly decreased in the soil-forming rock.

Of course, the surface filled up by clasters is not ideal; there are features of asymmetric distribution and accumulation of structural elements in some places but the whole surface is embraced by them. There is a correlation between the changes in the packing coefficient of structural elements at the inter-phase surface and the dynamics of changes in the structure compaction at a macrolevel (Fig. 2).

The accumulation of soil particles with definite topological dimension (d) has definite properties including changes in the compaction from the center to periphery, diverse morphometric parameters

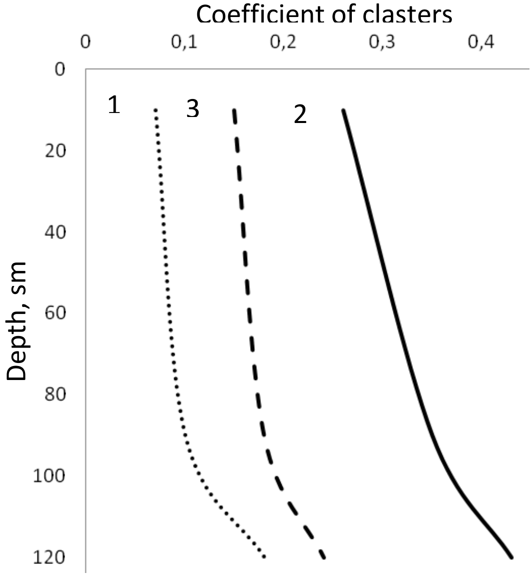

Fig. 2. Changes in the packing coefficient of clasters downwards the profile of the gray forest soil: 1 – primary precipitation (one drop of suspension), 2 – primary precipitation (2 drops) and 3 – double drying (one drop).

determining the structural state of the surface between phases, etc. When these properties become close to those characterized the clasters with topological dimension, the conditions for their further growth disappear. The factorial dimension is an energetic barrier; it is impossible to overcome this barrier under conditions that are far from the equilibrium.

The growth of fractal clasters serves as a cause for decreasing the amount of precipitated soil particles. The latter are usually combined with those parts of clasters that are available for contacts. The fractal boundary is winding and enriched with cavities which are not filled up by clasters and transformed into closed voids.

At the stage of increasing the fractal particles and formation of secondary structural elements in the course of precipitation the cavities are destructed and the total surface becomes enlarged, thus predetermining the clasters coagulation and the formation of more dense structures.

Having analyzed the experiment results, it was established that the size of structural elements is decreasing under the influence of soil draying. The dried soil samples in the course of precipitating their silt particles showed a tend towards decreasing the size of structural elements to be more compact in the humus horizon. Under identical conditions in the soil-forming rock there is no change in the claster size and the system state remains stable (Fig. 3).

In the experiment variant with precipitation of two suspension drops the secondary fractal formations appear and the first layer rema-

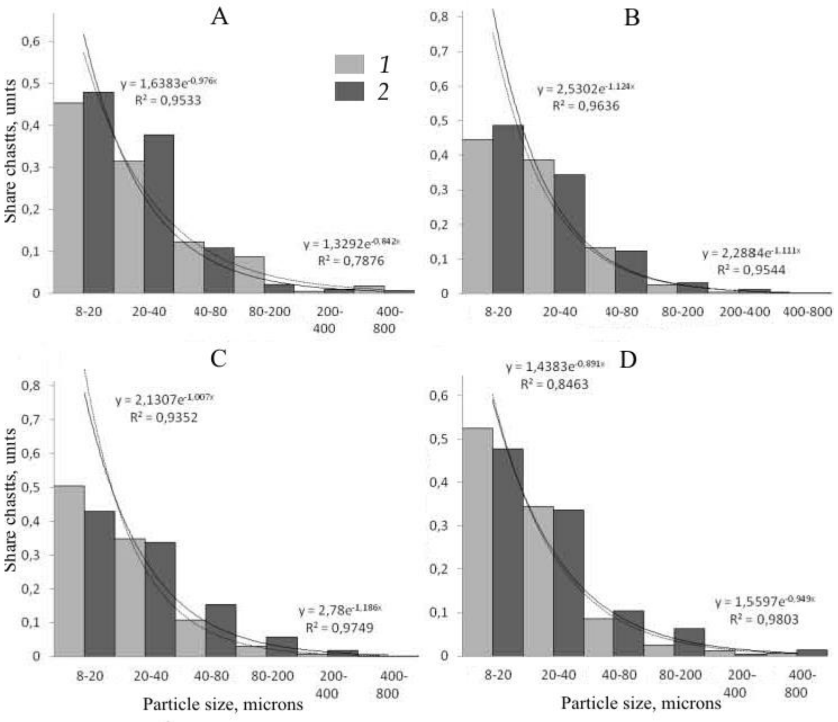

Fig. 3. Distribution of silt particles according to their size in the gray forest soil; precipitation of particles affected by drying (A, B) and double drying (C, D) in case of two drops (*1*, the first image) and one drop (*2*, second image): A – AY horizon, B – BTC horizon, C – AY horizon, D – BTC horizon; lines – exponential curves.

ins almost undisturbed. The Herst coefficient decreases to 0.39. The presence of the above cavities in fractal boundaries serves as evidence of differences in the composition, structure and properties between the central part and periphery of structural elements. The factor determining a complex of properties inherent to fractal clasters is a porous fractal structure. During the coagulation the structural elements are interacted with each other by means of the contact between adjacent surfaces. In this case the sites are formed in which the fine voids are combined in the boundary of adjacent clasters and serve as a generator for the development of microfissures.

CONCLUSION

An index of claster packing is proposed to be a basis for assessing changes in the soil dispersion and the soil structural state under the influence of seasonal drying. It was established that there is a tendency towards increasing the compaction of soil particles with decreasing their size, increasing their amount and declining the distance between the formed clasters. In the experiment variant with precipitation of soil particles affected by double drying the density of the developed structure in the humus horizon is increased at the expense of increasing the amount of clasters with decreasing their size. In the soil-forming rock the quantity of structural elements averaged in size decreases insignificantly. In the course of cyclic precipitation of fine-dispersed particles affected by drying the packing coefficient increases to 0.26 in the humus horizon and to 0.43 in the BTC horizon.

In case of developing the clasters of second order (cyclic precipitation) the dense distribution of structural elements is sharply increased being newly formed close to the surface in the field of their maximum concentration that can lead to irreversible changes in the soil microstructure and destruction of agronomically valuable soil aggregates. The conditions and time of precipitation have an influence on possible changes in the direction vector of dispersion and formation of its microstructure under dried conditions.

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