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GENESIS AND GEOGRAPHY OF SOILS

Clay Differentiation in Initially Homogeneous Substrates upon Long-term Field Experiments

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Abstract—Experimental data attesting to considerable spontaneous differentiation of the soil profile by the content and mineralogical composition of the clay fraction in the course of a 23-year-long field trial are analyzed. The experiment has been performed for three initially homogeneous substrates: loess soil, alluvial soil, and sandy soil. The highest relative rate of clay loss from the plow horizon is registered in the loess soil enriched in smectitic minerals. This loss reaches 0.9% of the initial clay content per year, or 20% per 23 years.

INTRODUCTION

Textural differentiation of a soil profile—the loss of clay particles from the upper soil horizon—is a firmly established phenomenon typical of the soils of humid regions. However, the particular mechanisms of clay loss, the conditions favoring the development of textural differentiation, and the kinetics of this process in tilled soils are open to argument. Some scientists believe that textural differentiation of soils is a modern and widespread process [1, 4]. Their opponents argue that the profiles of modern texturally differentiated soils are rather stable, and that textural differentiation in them has a relic character [8].

The conditions favoring the development of textural differentiation in tilled soils of humid zones are not quite clear. According to one of the concepts, the development of textural differentiation is only possible in soils subjected to seasonal waterlogging accompanied by gleyzation [2].

There are data attesting to considerable transformation of the crystallochemical composition and properties of fine earth fractions, especially the clay fraction, in conditions of agropedogenesis [9, 10]. This transformation may be induced by the application of mineral fertilizers. However, the opponents of the concept of textural differentiation of tilled soils argue that the modern character of changes in the mineralogy of the clay fraction has yet to be proved [7]. Micromorphological indices of textural differentiation (illuviation coatings) also cannot be considered a sufficient proof of the modern character of this process. Moreover, as noted by Rode [5], micromorphological indices of clay illuviation do not give any evidence for the overall effect of textural differentiation manifested by the difference in the texture of soil horizons.

It should be noted that the processes of textural differentiation in tilled soils are not taken into account by agronomists. For instance, the programs of long-term field experiments usually do not assume control over the changes in the particle-size composition of soil profiles.

In this context, the study of textural differentiation in tilled soils and the conditions favoring this process, as well as the search for direct indicators of textural differentiation, seem to be important tasks.

MATERIALS AND METHODS

Study Objects

The authors have studied textural differentiation in long-term field experiments with initially homogeneous substrates. These experiments were initiated in Germany in 1972 by the Institute of Vegetable Crop Production and Ornamental Flower Growing (Erfurt) and Humboldt University (Berlin) [16]. Three substrates of different textures were sampled from plowed sandy soil, loess chernozem-like soil (Wanzleben), and clayey alluvial soil (Golzow) in the middle reaches of the Odra River. These substrates were placed into concrete boxes (2 × 2 m with a height of 75 cm) supplied with draining holes at the bottom. A draining sandy layer (25 cm) was placed on the bottom and then covered by a soil layer with a thickness of 50 cm. Initially, the soil layer had a homogeneous textural composition. Some data on the properties of the studied soils at the beginning of the experiment (Table 1) can be obtained from [15, 16].

Crop rotation (vegetable crops), regulation of nutrition by fertilizers, and the required rates of irrigation have been maintained in the trials. Thus, the conditions

† Deceased.

of the experiment have been strictly controlled to avoid both desiccation and waterlogging of soils.

Methods

In the spring of 1996 (before the growing season), soil samples were taken by an auger from six boxes (two boxes characterizing the treatments without manure and with a minimal dose of nitrogen fertilizer (45 kg/ha annually) per each soil). The samples were taken in triplicate from the layers of 0–20, 20–30, 30–40, 40–50, 50–60, and 60–70 cm. After this, mixed samples (for similar horizons) were prepared. The particle-size composition of mixed samples was determined by the pipette method after pretreatment with sodium pyrophosphate and rubbing the soil paste. The following fractions were determined: 0.25–0.05, 0.05–0.01, 0.01–0.005, and 0.005–0.001 mm (according to Kachinskii), and <0.002 mm (according to Atterberg). The content of the fraction <0.0063 mm was calculated via interpolation.

The results of these determinations proved that initially homogeneous soils were subjected to textural differentiation. The removal of clay from upper soil horizons was interpreted as the result of agrogenic lessivage [6]. To verify this conclusion, additional soil sampling was made in the fall of 1996 according to the same scheme. The clay fraction (<0.001 mm) was separated on a centrifuge from samples characterizing the layers of 0–20, 30–40, and 60–70 cm. This fraction was then subjected to X-ray diffractometry, performed at the Laboratory of Geochemistry and Mineralogy of Soils in the Institute of Physicochemical and Biological Problems of Soil Science in Pushchino.

RESULTS

Differentiation of Soil Texture

Data on the initial (1972) content of the fraction <0.0063 mm can be obtained from [16]. As seen from Table 2, these data sharply differ from the data obtained by us in 1996. At the same time, the initial content of the fraction <0.0063 mm is rather close to the content of the fraction <0.002 mm in 1996. The difference in the results obtained in 1972 and 1996 is considerable. The reasons for this phenomenon are not quite certain. Partly, it can be due to the transformation of the soil mass during the experiment (23 years). Or, it may be partly an artifact related to the difference in analytical methods. It should be noted that the results obtained in 1996 (the particle-size distribution analysis was performed by analyst E.A. Agafonova in the Institute of Geography of the Russian Academy of Sciences) display a relatively low variation: 2–3% for sandy and silty fractions and 3–5% for the clay fraction.

However, even the lack of comparable data on the particle-size compositions of soils in 1972 and 1996 is not an obstacle to the main goal of our study. It is possible to trace textural differentiation of the soil profiles in 1996, taking into account that the initial textural composition of these soils was statistically homogeneous. For this purpose, it is important to find out statistically significant differences between the contents of certain particle-size fractions in the upper and bottom horizons of studied soils. Statistically insignificant differences for the rest of the fractions can be attributed to some random initial textural heterogeneity of the studied soil profiles. If statistically significant differences do exist, then they should find some plausible explanation.

Table 1. Initial properties of the substrates used in a long-term field trial “Kastenparzellenversuchsanlage” (Grossbeeren)

Soil type	FAT*, <0.0063 mm, %	Bulk density, g/cm^3	pH	C_{org}, %
Alluvial	23.9	1.31	7.6	1.3
Loess	17.2	1.36	7.5	1.5
Sand	5.5	1.45	6.6	0.55

*Initial content.

Table 2. Data on the contents of particle-size fractions in 1996 (averaged) and 1972

Fraction, mm	Kind of soil		
	alluvial	loess	sand
<0.0063*	34.93	23.6	7.69
<0.002*	27.55	17.16	5.48
FAT**	23.9	17.2	5.5

* Sampling in 1996. The analyses were performed at the Institute of Geography of the Russian Academy of Sciences.

** Sampling in 1972. The analyses were performed at the Humboldt University.

Textural differentiation of the soil profiles can be judged from data on the particle-size distribution analysis (Fig. 1). In order to verify the results, a variance analysis can be done for the distribution of different particle-size fractions by soil layers. The results of a monofactor variance analysis [3] prove that the upper layer (0–20 cm) of all the three soils is impoverished in clay (<0.001 mm) and enriched in sand (>0.05 mm) fractions. However, if we consider the results of this analysis for all particle-size fractions, the difference between the particle-size compositions of the upper and lower-lying horizons becomes statistically uncertain. This uncertainty can be due to random analytical errors in the determination of separate fractions. To minimize random errors, we can group separate fractions together, i.e., to consider the distribution of just three particle-size fractions (sand, silt, and clay).

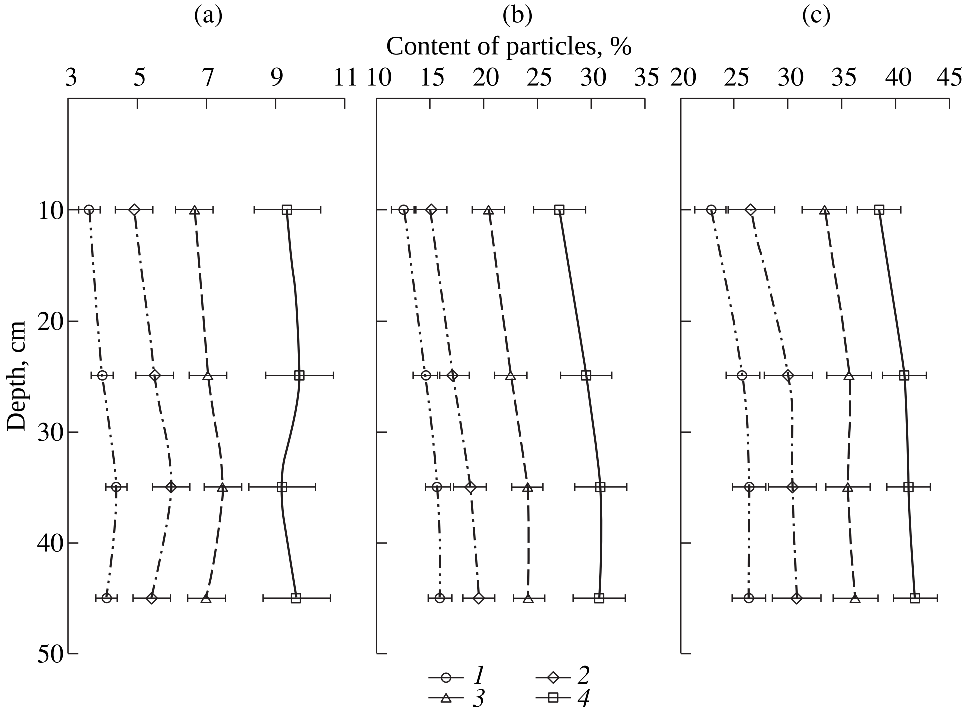

Fig. 1. Distribution patterns of particle-size fractions in the profiles of (a) sandy, (b) loess, and (c) alluvial soils. Size of fractions: (*1*) <0.001, (*2*) <0.002, (*3*) <0.005, and (*4*) <0.01 mm.

Initially, the lower limit of the silt fraction was set up by us at 0.002 mm. However, when this limit was lowered to 0.001 mm, the differentiation of the clay fraction (<0.001) along the soil profiles became more pronounced and statistically significant (Table 3).

Table 3. The results of the variance analysis of data on the particle-size distribution in experimental soils in 1996. The difference between the contents of particle-size fractions in the Ap layer (0–20 cm) and the layer that differs from the Ap most distinctly is assessed

Fractions, mm	Kind of soil					
	alluvial		loess		sand	
	t_Q^*	h_A^{**}	t_Q	h_A^2	t_Q	h_A^2
1.0–0.005	2.8	0.72	4.4	0.79	1.7	0.33
0.005–0.002	1	0.25	2.7	0.62	1.1	0.38
<0.002	4.1	0.77	9.9	0.95	4.3	0.74
<0.001	4.8	0.84	10.4	0.95	5.3	0.83

* The value of the Tukey test t_Q is used for comparing mean values of statistical groups of similar sizes. The critical level Q_{st} at α 5% is equal to 4.2 [3].

** The Snedekor criterion h_A^2 characterizes the contribution of factor A to the resulting value.

As follows from this table, the depletion of the Ap horizon by clay particles is statistically significant for all the three soils.[1] The quantitative effect (the Snedekor criterion) of the studied factor A (the depth of soil layer) on the statistical distribution of particle-size fractions exceeds quantitative effects of random factors (1 – A) by five times and more. This is especially true for the loess soil: A/(1 – A) = 19. In this soil, the depletion of clay from both the Ap (0–20 cm) and the lower-lying (20–30 cm) horizons is statistically significant. In other words, the redistribution of the clay fraction in this soil is clearly seen within the full thickness (50 cm) of loess. For the other particle-size fractions, the differences between the upper and lower lying horizons are statistically insignificant.

The results of the variance analysis allow us to estimate the degree of initial textural heterogeneity of studied soil profiles. It can be characterized by the random

[1] For the alluvial soil, the t_Q criterion (Tukey test) is somewhat lower than the critical (Q_{st} = 4.2) value, which may be due to the improper choice of the upper size limit (<0.002 mm) for the clay fraction. If the clay fraction <0.001 mm is considered, the t_Q value (4.7) is above the critical value. Thus, though the content of the fraction 0.002–0.001 mm does not exceed 6%, this fraction exerts strong negative influence on the results of determination of textural differentiation. In the alluvial soil, this fraction is randomly distributed in the soil mass, in contrast to the clay fraction (<0.001 mm). Random distribution of the fraction 0.002–0.001 mm can be judged from low values of the Tukey and Snedekor criteria (0.16 and 0.25, respectively).

factor of the variance with corresponding assessment of variation coefficients for separate particle-size fractions (Table 4).

As seen from Table 4, variation coefficients for most of the particle-size fractions have similar values (*V* = 6–10%). The sand fraction in the loess and sandy soils is an exception. In the sandy soil, the variation coefficient of this fraction is very low (*V* = 2%), which is conditioned by the predominance of this fraction (>80%) in the particle-size composition of sandy soil.

In the loess soil, the variation coefficient for the sand-size fraction is very high (*V* = 35%), which attests to some nonuniformity in the statistical distribution of this value, i.e., to its deviation from the normal distribution pattern. As the Tukey test for this fraction is higher than the critical level (4.2), a hypothesis of statistically insignificant differences in the sand content between separate layers of the loess soil (the zero-hypothesis) can be rejected. It means that the profile of this soil was initially heterogeneous with respect to the sand fraction content. This heterogeneity may be explained by the latent stratification of loess by the sand content, which was still preserved in the mixed loess material.[2]

Thus, the differentiation of the loess soil by the content of sand particles cannot be considered the result of textural differentiation in the course of the experiment. This phenomenon can be referred to as pseudodifferentiation. Partly, it may be explained by the real differentiation of the soil profile by the content of clay particles. The calculation of the Tukey test for the soil without clay (the elimination of the effect of clay differentiation) gives the t_Q value 3.2, i.e., below the critical level (4.2). It means that the relative accumulation of sand particles in the upper layer of loess soil can be attributed to two unidirectional factors: (a) random variation in the content of sand particles by separate soil layers, with its statistically significant accumulation in the upper layer and (b) regular decrease in the content of clay particles in the upper layer, with a corresponding increase in the relative content of sand particles. However, the main role is played by the first (random) factor. Therefore, this phenomenon cannot be considered the result of regular processes.

In general, the statistical analysis of particle-size distribution data reveals regular differentiation of all soil profiles by the content of clay fraction (<0.001 mm). The differentiation of soil profiles by the contents of the other particle-size fractions proves to be statistically unreliable. The clay content in the Ap layer (0–20 cm) is lower than in the other soil layers. The clay content in the layer of 20–30 cm is lower than that in the layer of 40–50 cm (Table 5). The most distinct textural differentiation is registered in the loess soil, for which most of

[2] The total mass of initial natural soil used in the experiment exceeded 200 tons. If there was some stratification in the initial soil, its complete homogenization would have required special technology. Unfortunately, the description of the experiment [16] does not contain data on the technology of soil mixing.

Table 4. Statistical assessment of the initial heterogeneity of substrates by the contents of sand, silt, and clay fractions (the contribution of random variable to the total variance)

Fractions	Kind of soil					
	alluvial		loess		sand	
	*SD**	*V***	*SD*	*V*	*SD*	*V*
Sand	2.55	6	5.6	35	1.6	2
Silt	1.45	6	5.4	8	1.3	10
Clay	2.12	7	1.1	6	0.5	10

* *SD*, standard deviation according to the variance analysis.
** *V*, coefficient of the variance, %.

the differences between the horizons are statistically significant. In the alluvial soil, the loss of clay from the Ap layer becomes statistically significant if the clay content in the Ap layer is compared with the clay content in the layers of 30–40 and 40–50 cm. In the sandy soil, the clay content in the Ap layer is only lower than that in the layer of 30–40 cm. In other words, textural differentiation of the sandy soil is restricted to the upper 40 cm of the soil profile. The removal of clay from the Ap layer corresponds to the relative accumulation of clay (if compared with the average clay content in the full soil thickness) in lower lying horizons. Thus, at least partial illuviation of clay particles into the lower-lying horizons can be assumed.

X-ray Diffractometry of Clay Material in the Studied Soil Profiles

In order to reveal the nature of textural differentiation, the mineralogy of the clay fraction was studied by X-ray diffractometry. The analysis was made using copper radiation (30 kV and 20 mA) and a rotation velocity of 0.1° per min. Oriented Mg-saturated clay films were prepared from a water suspension (20 mg clay + 10 drops of water) on glass slides 25 × 25 mm. X-ray diffraction patterns were obtained for Mg^{2+}-saturated air-dry specimens, as well as for clay films saturated with ethylene glycol and those heated at 300 and 550°C for two hours (Fig. 2). The results of peak size measurements were automatically processed by a special software program. Quantitative assessments of the contents of separate clay fractions were made on the basis of data on the areas under characteristic peaks from the samples saturated with ethylene glycol according to Biscaye [13]. Additional information was obtained from data on the difference in peak sizes between air-dry samples and heated samples, taking into account the changes in the intensity of the 1.0 nm peak upon soil heating.

The clay fraction from the loess soil is mainly composed of illite that constitutes from 72 to 79% of the total amount of clay minerals in this soil (Table 6). Judging from data on the ratios between the intensities

Table 5. Mean weighted contents of the main fractions in full soil profiles and deviations from the mean in separate horizons

Depth, cm	Kind of soil and size fractions								
	alluvial			loess			sand		
	clay	silt	sand	clay	silt	sand	clay	silt	sand
	Mean contents of fractions								
0–50	28.63	25.28	45.59	17.24	66.9	15.81	5.32	12.79	81.89
	Deviations from the mean								
0–20	–0.53	–0.28	2.45	–2.15	4.07	6.25	–0.43	–0.01	0.41
20–30	1.38	0.56	–1.73	–0.11	2.09	–1.92	0.17	0.7	–0.88
30–40	1.7	–0.42	–1.08	1.47	2.97	–4.63	0.64	–0.56	–0.08
40–50	2.12	0.15	–0.27	2.96	3.09	–6	0.07	–0.11	0.06

of reflections from 002 and 001 (Table 7), this mineral belongs to a group of easily weatherable minerals of the biotite–phlogopite sequence. The content of kaolinite reaches 10–17% of the total amount of clay minerals. The share of minerals with expandable lattices varies from 5 to 10%. These are mixed-layered minerals with alternating sequences of micaceous and expandable layers; micaceous layers predominate in their composi-

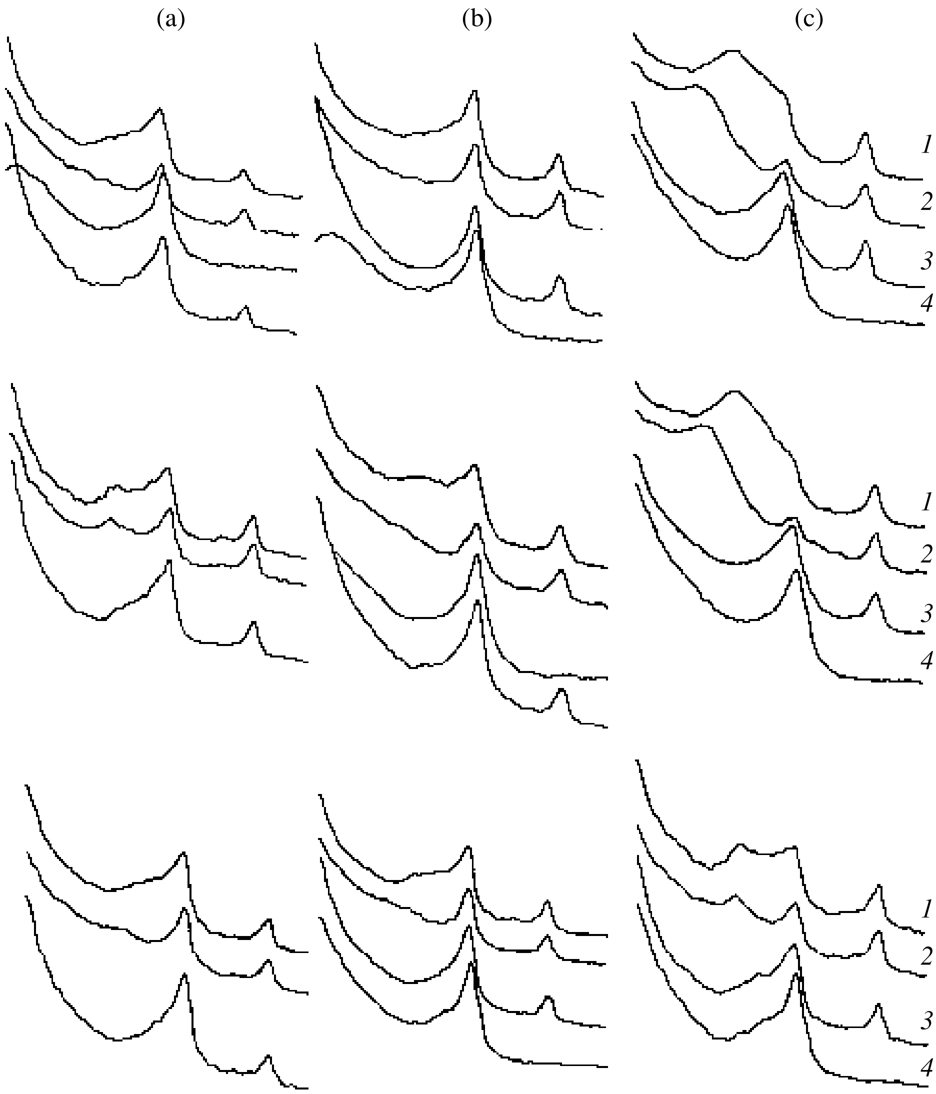

Fig. 2. X-ray diffraction patterns of the clay fraction (<0.001 mm) from (a) sandy, (b) loess, and (c) alluvial soils. Pretreatments: (*1*) air-dry samples, (*2*) saturation with ethylene glycol, (*3*) heating at 300°C, and (*4*) heating at 550°C.

Table 6. The proportions between different clay minerals in the clay fraction of soils

Kind of soil	Depth, cm	Peak areas, nm			Groups of minerals, % of the total clay content			Ratios of minerals with expandable lattices to illite*
		1.4–1.8	1.0	7.2	swelling	illite	kaolinite	
Alluvial	0–20	23	20	13	41.4	35.7	23.2	1.15
	30–40	35.5	12	11	*60.7*	20.5	18.8	2.96
	60–70	8	42	8	13.8	72.4	13.8	0.19
Loess	0–20	4	66	14	4.8(4)	78.5	16.7	0.11(0.07)
	30–40	10	48	9	*14.9(9)*	71.6	13.4	0.21(0.16)
	60–70	8	62	8	10.3(11)	79.4	10.3	0.13(0.20)
Sand	0–20	5	64	8	6.5(5)	83.1	10.4	0.08(0.08)
	30–40	5.5	66	10	6.7(6)	81	12.3	0.08(0.10)
	60–70	9.5	52	11	*13.1(9)*	71.7	15.2	0.18(0.17)

Note: The values attesting to the translocation of minerals with expandable lattices are given in italics.
* The values calculated on the basis of data on the intensities of diffraction peaks are given in parentheses.

tion. An increase in the intensity of the 1.0 nm peak after heating attests to the presence of smectitic layers. At the same time, incomplete expansion of mineral lattices after saturation with ethylene glycol allows us to assume the presence of vermiculitic and chloritic layers. The presence of these layers is also confirmed by the low intensity of the reflection at 0.485 nm. The low intensity of this peak and the absence of a distinct maximum of the reflection after saturation of the clay sample with ethylene glycol attest to a great degree of dispersion of mixed-layered minerals with expandable layers. The amount of these minerals in the upper soil layer (0–20 cm) is about 5% of the total amount of clay minerals. In the lower-lying horizon, it increases by three times and reaches 15%. The ratio of mixed-layered minerals to the illite changes from 0.11 in the Ap layer to 0.21 in the lower-lying horizon.

The clay fraction from the sandy soil consists of the same minerals. Moreover, relative proportions between them are approximately the same as those in the loess soil (Table 6). Along with these minerals, there is some amount of chlorite–vermiculite, diagnosed by the peaks at d/n 1.36–1.43 nm obtained from the air-dry samples and the peak at 1.23 nm obtained from the heated samples. In contrast to the loess soil, there is no decrease in the content of mica–smectitic (or vermiculitic) minerals in the Ap horizon. At the same time, the amount of these minerals increases significantly (up to 13%) in the underlying layer (Table 6). Hence, the ratio of the minerals with expandable lattice to illite increases from 0.08 in the layers of 0–20 and 30–40 cm to 0.18 in the layer of 60–70 cm.

The clay fraction from the alluvial soil contains illite, kaolinite, and a considerable amount (40–60%) of mixed-layered mica–smectitic minerals with a predominance of smectitic layers (Table 6). The latter are diagnosed by a wide peak at 1.4 nm for air-dry samples that shifts to 1.8 nm in the samples saturated with ethylene glycol and to 1.0 nm after calcination. The width of this peak and its flattened summit attest to a great degree of mineral dispersion and somewhat disordered crystal structure. It is interesting to note that the disordering of mica–smectitic minerals is better manifested in the layer of 30–40 cm as compared to that in the Ap layer. The amount of minerals with expandable lattice in the Ap horizon (41%) is lower than that in deeper horizons (up to 61%). The ratio of the minerals with expandable lattice to illite increases from 1.15 in the Ap layer to 2.96 in the layer of 30–40 cm.

DISCUSSION

The loss of clay particles from the Ap layer (textural differentiation) can only be explained by the downward migration of clay material in suspensions. The removal of clay particles from the upper part of soil profiles (eluviation of clay) is accompanied by their accumulation in lower lying horizons, including the sandy draining layer (illuviation of clay). The accumulation of clay in the sandy layer is especially pronounced in the loess soil with the highest degree of textural differentiation. Unfortunately, the samples from the sandy layer were only taken in duplicate, and the size of statistical sample for this layer is insufficient for definite conclusions.

The eluvial–illuvial distribution pattern of the clay fraction is in agreement with the results of mineralogical analysis of this fraction. In all the soils studied, surface horizons contain lower amounts of minerals with expandable lattice in comparison with deeper horizons. The degree of dispersion (fineness) of clay minerals is very high, especially in the subsurface horizons. The percentage of different clay minerals calculated per bulk soil mass (Table 7) shows that the content of the minerals with stiff structures (kaolinite and illite) in the upper horizons is rather stable or slightly increases in the uppermost horizon, owing to a decrease in the

Table 7. Changes in the contents of separate groups of clay minerals along the soil profiles

Kind of soil	Depth, cm	Swelling minerals	Illite	Kaolinite
Alluvial	0–20	37/8.89	32.1/7.7	20.9/5
	30–40	*54.6/13.63*	18.4/4.6	16.9/4.2
	60–70	11.9/*0.48*	62.5/2.5	11.9/0.5
Loess	0–20	4.3/0.73	69.6/12	14.8/2.6
	30–40	*13.3/2.41*	63.9/12	12/2.2
	60–70	9.1/0.59	70.2/4.5	9.1/0.6
Sand	0–20	5.4/*0.24*	*68.5*/3.1	8.6/0.4
	30–40	5.6/*0.29*	68.5/3.5	10.4/0.5
	60–70	*11.6/0.51*	63.5/2.8	13.5/0.6

Note: In front of the slash, % of the weight of clay fraction; behind the slash, % of the bulk soil weight.

amount of labile mica–smectitic (or vermiculitic) minerals. Labile minerals with an expandable lattice participate in the downward migration and accumulate in lower lying soil horizons or in the draining sandy layer. Thus, the development of textural differentiation is mainly due to these minerals. This is explained by their smaller size in comparison with the minerals having stiff structures. Especially fine (superdispersed) minerals tend to accumulate in illuvial horizons. The width of the first diffraction peak (at 1.0 nm) that characterizes the degree of disordering of the crystal structure of clay minerals gains maximum values in a layer of 30–40 cm for the alluvial and loess soils and in a layer of 60–70 cm for the sandy soil, i.e., in the layers enriched in mica–smectitic minerals. It is probable that the accumulation of the finest and somewhat disordered illite also takes place in these layers. The most significant loss of clay minerals with expandable lattices from the Ap layer and their accumulation in deeper horizons are registered in the loess soil (the loss of these minerals from the Ap horizon reaches 53%). The minimal loss (20%) is inherent in the alluvial soil. In the sandy soil, the loss of these minerals (35%) is observed in the surface and subsurface horizons.

Table 8. Some X-ray parameters of illite minerals in the profiles of studied soils

Kind of soil	Depth, cm	I_{002}/I_{001}	1/2 of the width of a peak at 1.0 nm
Alluvial	0–20	0.49	1.63
	30–40	0.54	*1.81*
	60–70	0.54	1.56
Loess	0–20	0.4	1.24
	30–40	0.46	*1.65*
	60–70	0.43	1.15
Sand	0–20	0.44	1.42
	30–40	0.44	1.32
	60–70	0.51	*1.55*

Thus, quantitative data on clay mineralogy and peculiarities of X-ray diffraction patterns of clay minerals in different soil layers attest to the redistribution of clay minerals along the profiles of all studied soils. The most active migration is characteristic of fine-dispersed minerals of the mica–smectitic (or vermiculitic) type and, probably, fine-dispersed and relatively disordered illite particles. The maximum loss of minerals with expandable lattices from the upper soil layer is observed in the loess soil, with medium loss in the sandy soil and the minimum loss in the alluvial soil. Taking into account the character of clay minerals in the studied soils, it can be supposed that the main mechanism of clay loss is the downward migration of clay particles in suspensions. Several factors may contribute to this process: additional soil moistening, partial mechanical breakage of microaggregates in the course of tillage operations, and the neutral reaction of soil solutions that contributes to the stability of suspensions.

It is possible to calculate the rates of clay loss from the Ap layer of studied soils. Annual removal of clay from this layer constitutes 0.05, 0.23, and 0.30 kg/m^2 for the sandy, loess, and alluvial soils, respectively. However, the values of the relative loss of clay (percent of the initial amount) are more close to one another, ranging from 0.6 to 0.9% per year (Fig. 3). It is probable that our assessments of the loss of clay may be somewhat underestimated, as they do not take into account the migration of clay beyond the soil profiles. At the same time, the rates of clay loss obtained by us are at least an order of magnitude higher than the estimates of clay loss obtained for natural soil profiles [1, 4, 12, 14, 17, 18]. In comparison with such a great difference, some variations in the values of the relative loss of clay obtained by us seem to be insignificant. The high rate of clay loss in the experiment may be explained by regular perturbation of the plow layer by different tillage operations; as a result of tillage, the rearrangement of soil structure and microstructure takes place, and the

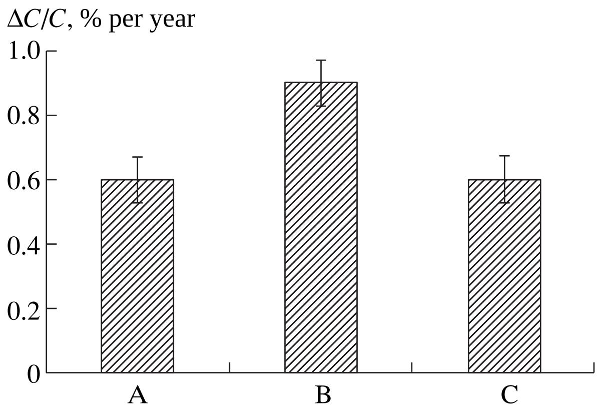

Fig. 3. The rates of annual removal (Δ*C*) of clay (<0.001 mm) from the Ap (0–20 cm) horizon of (A) sandy, (B) loess, and (C) alluvial soils calculated in percent of the initial clay content *C* (calculated as the mean clay content in the layer of 0–50 cm).

loci of intensive peptization of clay particles appear in the soil matrix.

Thus, it may be concluded that the textural differentiation of studied soils is due to lessivage (the mechanical migration of clay particles in suspensions) [11, 14]. The contribution of gley processes to textural differentiation could not be significant in the studied soils. The hypothesis of acid hydrolysis of clay minerals in the Ap layer (podzolization) can also be rejected because of the neutral reaction of soil solution, high base saturation, and constant renewal of humic substances in conditions of the experiment.

CONCLUSIONS

(1) Textural differentiation of initially homogeneous artificial soils with low organic matter content took place in the course of a long-term (23–24 years) field experiment with strictly controlled conditions.

(2) The main mechanism of textural differentiation is connected with the migration of fine (<0.001 mm) clay particles in suspensions. The eluvial–illuvial redistribution of clay is most pronounced for the finest clay minerals, represented by the particles of mica–smectitic (vermiculitic) type and, probably, by somewhat disordered illite particles.

(3) The processes of textural differentiation developed in three different types of substrates (from sands to clay silty loams) with different compositions of clay minerals (from the predominance of smectite to the predominance of illite).

(4) The absolute (up to 0.3 kg clay/m^2 per year) and relative (0.6–0.9% of the initial clay content) rates of clay (<0.001 mm) loss from the Ap layer are established. The results obtained do not allow us to make definite conclusions about the changes in the rate of clay loss in the course of the experiment. It can be assumed that the rate of this process remained relatively stable during the whole period of the experiment. At the same time, some qualitative indices suggest that the rate of clay loss from the loess soil increased somewhat throughout the time of the experiment.

(5) Application of statistical criteria allowed us to distinguish between regular and irregular changes in the contents of separate particle-size fractions along the soil profiles. This approach seems to be promising for the study of pedogenetic process both in tilled and natural soils.

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