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Agrogenic evolution of soddy-podzolic soil: Feasibility of repeated re-involvement in cultivation of the fallow lands formed on band clays

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Abstract

Transformations of the soddy-podzolic gleyic clay soil in a long-term agricultural use (> 200 years) was studied in Leningrad region, northwest Russia. This feasibility study investigated the possibility of re-cultivation of these soils after long term fallowing. Morphological structure, particle size distribution, content and ratio of ferrous and oxide forms of iron in the profile of virgin (indigenous forest) and arable drained soil were analysed. In addition, changes in the organogenic-profile were traced in the course of long-term agrogenesis (> 200 years). In virgin forest soil, during its pedogenesis the loss of fractions <0.01 mm from the eluvial layer was 877.4 kg m^{-2}, and the loss of <0.0001mm was 287.5 kg m^{-2}, as compared with parent material not affected by the processes of pedogenesis. However, long-term agrogenesis (>200 years) led to increased eluvial losses of fine earth particles. The loss of fraction <0.01 mm from the arable horizons was 1244.8, and < 0.0001 mm was 570 kg m^{-2}, respectively. This was due to multiple yearly tillage that increased the porosity of the soil and thus intensified lessivage, which led to increased leaching and eluvial losses. The total loss of colloids from the entire profile of virgin soil was 262.1 kg m^{-2}, and from the arable layer of drained soil - 290.1 kg m^{-2}. The humus enrichment of the colloids of the plough (P) horizon of the arable soil was two times lower than that of the surface (AY) horizon of the virgin soil. The relative share of the participation of colloids in the fixation of humus by the soil was the same (11.6 and 10.9%, respectively). In the subsurface horizons, the absolute content of humus in the colloids decreased, and the share of participation in the fixation of humus increased. When soddy-podzolic gleyic clay soil is brought to cultivation then the water-air regime is improved, content and composition of humus, depth of arable horizon is increased and the soil acidity decreased. At the same time the leaching of fine earth materials is accelerated. When this soil was withdrawn from crop production, the positive changes achieved as a result of cultivation were gradually lost. For the first time we could qualitatively calculate the losses of the fine earth fractions for the given soil from top soil. Taking into account the high costs of re-cultivation of the former land and a high cost of re-installation and maintenance of an optimal hydrological regime (drainage network) we concluded that repeated ploughing and involvement of arable soddy-podzolic gleyic clay soil into cultivation is economically unreasonable.

Keywords: soddy-podzolic clay soil, agrogenic evolution, fine-dispersed fraction, organogenic-mineral profile, colloids

Introduction

Soils formed on band clays are widespread in the west and north-west of Russia in the areas of lakes Onega, Ladoga, Ilmen, etc. In different years, the study of soil formation processes in these soils was studied by Gagarina (1994), Ivanov and Yanko (2019), Matinian et al., (1983), Karavaeva, (1996), Karavaeva (2000), Khantulev et al., (1977), Pestryakov (1977), Shoba et al., (1983), Sokolova et al (1983), Zvereva et al., (1990), Zvereva and Lazareva (1989), Zaydelman (1985). To date, the literature has accumulated a certain factual material devoted to the change in the conservative properties of soils of this genesis under the influence of prolonged agrogenesis (total chemical, particle size distribution and mineralogical compositions) (Litvinovich et al., 2021; Matinyan et al., 1983; Nikolaev et al., 2021; Shein et al., 2009; Shein et al., 2021; Shevchenko et al., 2020). Nevertheless, this information cannot be considered completely exhaustive. Thus, it is considered established that in the process of soil formation in clay substrates there are processes of chemical destruction and physical crushing of particles of fine earth (Gagarina 1994; Karavaeva 2000), which can lead to replenishment of the silty fraction ("silt formation"), but mathematical models for describing this process have not been developed. Nor can the data on the contribution of finely dispersed fractions of turf-podzolic clay soils in the fixation of humus substances be considered sufficiently complete.

The hydrothermal regime of sod-podzolic gleyy clay soils on band clays is characterized by seasonal waterlogging and associated development of the gley process. In the formation of gley, the main role is played by the processes of iron reduction during the decomposition of organic substances in conditions of abundance of moisture and lack of oxygen in the air (Kaurichev and Nozdrunova 1964). When this soil is drained, the processes of iron reduction are attenuated. There are scarce works devoted to the establishment of the content and ratio of ferrous and oxide forms of iron in individual horizons of the profile of native soddy-podzolic gleyic clay soils and their transformation during the laying of a closed drainage network and in a long-term agrogenesis.

During the cultivation of these soils, changes occur in different directions: its water-physical and chemical properties are improved mainly due to the laying of a drainage system and the introduction of appropriate fertilizers and liming. But at the same time, destruction of the colloidal complex and its loss from the arable horizon can occur.

The deep systemic crisis since the early 1990s in Russia has led to the fact that the overwhelming amount of previously drained clay soils of agricultural land has been withdrawn from crop production and are at various ages of fallowing. The amount of fertilizers used on cultivated soils has sharply decreased, liming has stopped.

The new agricultural strategy of Russia assumes re-involvement of 12 million hectares of former croplands into economic circulation again in the period of 2021-2030. Great importance is given to the development of soil reclamation with the mandatory reconstruction of the drainage system, the use of new materials in the construction of drainage, as well as modern technologies for the removal and utilization of woody and shrubby vegetation. This requires a comprehensive assessment of the transformation of soil properties during the period of active use in culture and the economic feasibility of their re-cultivation. Therefore, the study tasks included:

- to establish the influence of long-term agricultural use of soddy-podzolic clay soil on the morphological structure of the profile
- determine the content and ratio of ferrous and oxide forms of iron in individual horizons of virgin and arable drained soil
- to identify changes in the content of fine particles in the process of natural and agrogenic soil formation and develop empirical models describing the transformation of finely dispersed fractions in the soil profile of a given genesis
- calculate the loss of fine soil from virgin and arable clay soils
- to study the change in the natural organoprofile in the process of long-term operation of drained soddy-podzolic clay soil; to find out the contribution of colloidal and pre-colloid fractions in the fixation of humus substances
- assess the feasibility of re-cultivation the soils of this genesis after their prolonged fallowing

Materials and methods

Site description

To identify changes in the composition and properties of soils in the process of natural soil formation and long-term agrogenesis, a comparative geographical method of a conjugate study of virgin and arable turf-podzolic clay clay dusty-silty soils formed in similar geomorphological conditions on the territory of the Prinevskaya lowland (Leningrad region) was used.

The average annual rainfall is 600-650 mm. The amount of evaporation is not more than 400 mm. Excess precipitation over evaporation is one of the main reasons for the formation of soils of temporary excessive moisture. Soil-forming rocks within the territory under consideration, formed by the activity of the glacier, are represented by lake-glacial band clays. The latter are characterized by high water absorption, low water retention and water permeability, which, along with a significant excess of precipitation over evaporation and imbalance in natural drainage, causes waterlogging of soils heavy in terms of particle size distribution and causes unfavorable conditions of water, air and nutrient regimes.

Arable soddy-podzolic clay soil is located 34 km from St. Petersburg (former sovkhoz Detskoselsky). It has been in culture for more than 200 years. It is not possible to reconstruct the history of land use over the years. It is known that before the 1917 there was a rich village on the site of the modern massif. The soil was used for grazing cattle and hayfields. Re-development of the soil began after the Second World War. In 1959, a pottery drainage was laid with a distance between the drains of 10-12 meters. The depth of the drainage system is 90-100 cm. A six-field crop rotation, where three of them were perennial grasses was used. The high level of agricultural technology, characteristic of suburban farms of the Leningrad region, made it possible to obtain in 1976-1980 on the massif: vegetables - 30.8 tons ha^{-1}, fodder root crops - 50.8 t ha^{-1}, hay of perennial grasses - 6.5 t ha^{-1}. Soil profiles was laid out in 1983 on the perennial grass plots. In 1989, the drainage failed. Since 1990, the soil has been used for hayfields for a short time. Currently, the massif is a weakly planted variegated grass meadow, gradually undergoing waterlogging.

The virgin soddy-podzolic clay soil is located in the immediate vicinity of arable soil and is occupied by secondary forest. The vegetation cover is represented by alder (*Alnus*, L.), aspen (*Populus tremuloides*, L.) and birch (*Betula*, L.). The grassy cover is continuous, with a predominance of sedge (*Cyperaceae*, L.).

The particle size distribution of parent rocks indicate that the soils are formed on a material similar in composition (Table 1).

Table 1. Particle size distribution of soddy-podzolic gleyey clay virgin and arable soil

Horizon	Depth	1-0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	<0.001	<0.01
	cm				mm			
				Virgin				
AY	3-10	4.3	21.1	24.2	20.0	18.0	12.4	50.0
ELg	10-20	7.8	19.9	21.6	17.1	22.6	11.0	50.7
BTg	20-30	6.4	12.3	23.0	17.2	22.6	18.5	58.3
BTg	30-40	6.1	12.6	23.8	16.4	21.4	19.7	57.5
BTg	50-60	7.0	11.7	22.0	18.2	21.7	19.4	59.3
BTg	60-70	6.9	11.8	21.5	18.7	22.1	19.0	59.8
BTg	70-80	7.2	10.0	22.1	22.4	19.5	18.8	60.7
Cg	120-130	7.4	9.8	23.0	21.5	19.4	18.9	59.8
				Arable				
P	0-10	4.9	22.1	23.2	18.9	20.9	12.0	51.8
P	10-20	4.4	23.0	23.7	18.0	21.1	11.8	50.9
P	20-30	5.1	21.9	22.5	17.9	21.4	12.2	51.5
BELg	30-40	7.5	15.0	23.9	15.5	16.5	21.6	54.6
BELg	40-55	8.4	18.9	19.7	13.2	17.5	22.3	53.0
BTg	60-70	8.1	13.4	22.0	16.4	18.6	21.5	55.0
BTg	80-90	8.0	10.9	23.2	19.0	18.4	20.5	57.9
Cg	130-140	8.6	10.7	23.2	18.6	18.8	20.1	57.5

Methods

The method of cutting cylinders (100 cm^3) was used to determine the bulk density. The particle size distribution was determined following wet dispersion with the pipette method. The isolation of fine fractions was determined as follows: the fraction <0.001 mm was divided into pre-colloidal and colloidal (<0.0001 mm) phases using a C-100 flow-through centrifuge at 20 thousand rpm. The suspension was coagulated with an HCl solution (Gorbunov 1971). The content of soil humus was determined using the wet combustion method. Oxides of ferrous and trivalent iron were determined by the complexometric method (Novitsky et al 2021).

Results and discussion

Morphology

The structure of the profile of virgin forest soil is typical for soils of this genesis. The upper part is a forest litter (O - 0-3 cm), well mixed with mineral mass. Below is a shallow grey-humus horizon (AY - 3-10 cm), homogeneous dark gray color, densely intertwined with plant roots. At a depth of 10-20 cm, a podzolic horizon (ELg) is formed, whitish in color with small grayish layers and spots of gleying. Below, at a depth of 20-80 cm, there is an illuvial-textured clay horizon (BTg). Soil-forming rock (C) lies from 80 cm depth.

The development and structure of arable soil was formed under the influence of the agrogenic process of soil formation. Soil cultivation, systematic fertilization, liming, crop rotation, engineering land reclamation transform the upper part of the soil profile to the depth of plowing with the formation of an arable layer and the involvement in its composition of the horizons AY, ELg and part of the BTg horizon. The arable layer (P - 0-30 cm) is characterized by uniform dark gray coloring, lumpy structure, densely permeated with the roots of herbaceous vegetation.

Under the influence of agrogenic soil formation in the profile of arable soil, the BELg eluvial horizon (30-55 cm) is formed, which corresponds to the depth of the upper part of the BTg horizon whose depth is 55-90 cm. The change in the hydrological regime due to drainage led to a weakening of the signs of gleying to the depth of the drainage. A similar morphological structure of the middle and lower part of the profile of virgin and arable soils indicates the development of the same processes in cultivated soil as in virgin soil.

Content and ratio of ferrous and oxide forms of iron in the studied soils

Due to the prevailing water-air and oxidative conditions in clay soils, the transformation and redistribution of various forms of iron occur (Table 2). Insoluble forms, represented by crystallized and amorphous non-silicate iron, pass into more mobile compounds of hydroxide of ferrous oxide and oxide and its simple salts (Gorbunov 1971). The studied soils are characterized by a significant content of oxide forms of iron in the entire soil stratum, which gives a characteristic color to their profile. The greatest amount of ferrous oxide is found in forest soil.

There are five groups of iron oxide compounds in soils distinguished. They give a characteristic color to gleyed soils: water-soluble ionic or complex iron; active, represented by precipitated insoluble forms and partly forms of firmly adsorbed by clay minerals; inactive iron, firmly adsorbed by clays, as well as partially iron minerals and some of its insoluble forms; non-extractable iron bound to and contained in clay minerals (Patrick and Turner 1968).

Table 2. Content and distribution of ferrous and oxide forms of iron in soddy podzolic gleyey clay soils

Horizon	Depth, cm	Fe_2O_3	FeO	Fe_2O_3 / FeO
		Virgin		
AY	3-10	1.65	1.21	1.36
ELg	10-20	2.60	1.04	2.50
BTg	30-40	2.89	1.44	2.01
Cg	120-130	2.53	1.47	1.72
		Arable		
P	0-30	2.32	0.99	2.34
BELg	40-50	3.12	0.69	4.52
BTg	70-80	3.03	0.92	3.29
Cg	130-140	3.88	0.93	4.17

When waterlogged soils are drained, ferrous iron is oxidized. Drainage leads to a decrease in the content of ferrous oxide and an increase in its oxide form. The ratio of oxidized and reduced forms of iron in arable soil is expanded. Color signs of glaciation are weakened (Table 2).

However, the complete disappearance of ferrous oxide forms during drainage could not be achieved. This is because not all forms of ferrous oxide are easily oxidized. Active and inactive iron are stable forms and even in air these forms retain their specific color. For the complete disappearance of color signs of glaciation, apparently, a significant period of time is needed.

In general, cultivation and drainage lead to an expansion of the ratio of oxidized and reduced forms of iron in arable soil, which indicates an improvement in the water-air regime and the predominance of oxidation processes in the profile. However, gleying during the drainage of soils of this genesis is not completely eliminated.

Particle size distribution

Particle size distribution shows that the profile of the studied soils is quite clearly differentiated in the content of clay and silty fraction (Table 1). The eluvial zone in virgin forest soil covers a layer of 3-20 cm (AY and ELg). Down the profile in the BTg horizon, the silt and physical clay content increases substantially from 11.0 to 18.5% and 50.7% to 58.3%, respectively. Further, in the deeper layers, the content of clay particles and silt fraction is leveled.

Long-term agrogenesis changed the horizontal structure of the profile of soddy-podzolic clay soil. The eluvial horizon is the entire arable layer (0-30 cm), which is evenly depleted of silt and clay fraction. The BELg transition horizon, located at a depth of 30-55 cm and formed at the site of the illuvial horizon BTg of virgin soil, is also affected by eluvial processes. A decrease in the content of the medium (0.01-0.005 mm) and fine (0.005-0.001 mm) dust in the process of agrogenic soil formation was revealed. In the BELg horizon, the number of these particles is minimal compared to all other soil layers.

The loss of fractions of fine and medium dust in agrogenic soil may well be caused by downward migration through pores and cracks with leaking moisture. According to Motomura (1969), increasing the downward flow of moisture due to drainage contributes to the increased migration of fine soil from the upper horizons of the profile. According to Seidelman (1985), the water permeability of soddy-podzolic soils under the influence of drainage starting from the surface is 1.7-2 times greater than that of an undrained one.

On the other hand, according to Gagarina (1994), the main mechanism for the loss of dusty fractions in soddy-podzolic clay soils is a physical distraction of clastogenic clay minerals, including trioctahedral, kaolinite and hydromica.

Calculation of the correlation coefficient between the content of medium dust and silt fraction, as well as fine dust and silt particles, did not reveal a significant relationship between them. However, this does not mean that the processes of physical and chemical destruction of dusty fractions in the profile of virgin forest soil are delayed at the stage: the medium-dust and fine dust does not lead to replenishment of the content of silty particles. Probably, the ratio of silt intake as a result of "silt formation" and its downward migration in solutions and suspensions is formed in virgin forest soil in favor of the latter. Zvereva and Lazareva (1989) in studying the silt sub-fractions showed the predominance of water-peptized silt (> 90 %).

The calculation of the balance of fractions <0.001 and <0.01 mm, performed for virgin forest soil, showed that the total losses of clay particles from the eluvial layer amounted to 877 kg m^{-2}, silty fraction - 287.5 kg m^{-2}. There wasn't revealed illuvial accumulation of physical clay and silt (Tables 3 and 4).

Table 3. Balance of the fraction <0.001 mm in the profile of soddy-podzolic clay soil

Horizon	Depth, cm	Bulk density, g cm^{-3}	fraction < 0.001 mm		*output-accumulation, g cm^{-3}	Sum of output-accumulation, kg m^{-2}
			%	g cm^{-3}		
			Virgin			
AY	7	1.02	12.4	12.6	– 19.5	- 136.5
ELg	10	1.55	11.0	17.0	– 15.1	- 151.0
BTg	38	1.68	19.1	32.1	0	0
Cg	–	1.70	18.9	32.1	–	–
			Arable			
P	30	1.29	12.0	15.5	– 19.0	– 570.0
BELg	25	1.64	21.9	35.9	+ 1.4	+ 35.0
BTg	45	1.71	20.7	35.4	+ 0.9	+ 40.5
Cg	–	1.72	20.1	34.5	–	–

* The calculation was carried out for equal in depth layers compared to the parent rock

Table 4. Balance of the fraction <0.01 mm in the profile of soddy-podzolic clay soil

Horizon	Depth, cm	Bulk density, g cm^{-3}	fraction < 0.01 mm		* output-accumulation, g cm^{-3}	Sum of output-accumulation, kg m^{-2}
			%	g cm^{-3}		
			Virgin			
AY	7	1.02	50.4	51.4	– 50.26	– 351.8
ELg	10	1.55	50.7	78.6	– 23.00	– 230.0
BTg	38	1.68	59.1	99.3	– 2.37	– 90.0
Cg	–	1.70	59.8	101.6	–	–
			Arable			
P	30	1.29	51.4	66.3	– 32.60	– 978.0
BELg	25	1.64	53.8	88.2	– 10.67	– 266.8
BTg	45	1.71	56.4	96.4	– 2.46	–110.7
Cg	–	1.72	57.5	98.9	–	–

* The calculation was carried out for equal in depth layers compared to the parent rock

The process of physical and chemical destruction of dusty fractions in arable soil was most active. This is evidenced by a sharp decrease in the content of fractions of medium and fine dust starting from a depth of 30-40 cm. At the same time, an increase in the content of the silt fraction was established at this depth (Table 1).

Probably, the silt content in arable drained soil is strongly related to the content of fine dust and to a lesser extent to the content of medium dust. Probably, as a result of the destruction of medium dust particles in the profile of arable soil, there was a replenishment of mainly fine dust particles, which, in turn, collapsing, replenish the supply of silty fraction. So, the transformation of dusty particles to the size of a silt fraction has a cascade pattern.

The process of physical and chemical destruction (dispersion) of dusty fractions takes place in both soils. However, the intensity of these processes in the profile of drained soil of long-term agricultural use is higher. Eluvial losses of physical clay and silt with prolonged agrogenesis and drainage were enhanced. This is evidenced by the shift of the illuvial maxima of silt (deepening of the illuvial layer) down from the border of ploughing (Table 1). The loss of clay particles from the horizons P and BELg was 1244.8 kg m^{-2} (Table 4). Losses of silt fraction were 570 kg m^{-2} (Table 3).

Thus, in arable drained soil, the processes of destruction of clay and silty fractions in the illuvial stratum are not only not weakened, but, on the contrary, enhanced. This is all the more obvious if we bear in mind that the arable layer in the process of its creation was enriched with fine earth from the upper part of the illuvial layer of virgin soil and experienced a regular introduction of fertilizers and lime. As a result, a decrease in the content of particles of medium and fine dust with simultaneous enrichment of the illuvial stratum with the silty fraction occurred.

Illuvial accumulation of silt in the horizons BELg and BTg was 35 and 40.5 kg m^{-2}, respectively (Table 3). It is likely that in this part of the profile, the processes of silt inflow as a result of migration from the upper layers and the "silt formation" as a result of physical crushing and chemical destruction of dusty fractions compensate for its removal in solutions and suspensions, which leads to an increase in the silty fraction content in the illuvial layers.

The constant replenishment of the already heavy mass of the sub-arable layer with silt is a negative phenomenon, since it leads to colmatation (silting) of these horizons. The redistribution of moisture to the deep horizons of the profile is disturbed. The network of cracks created during loosening is reduced. The role of the illuvial stratum as a water table is enhanced. All this leads to the need for regular deep reclamation loosening of drained clay soils, the positive effect of which is exhausted after 1 year Motomura (1969).

The content and distribution of the colloidal fraction in the profile of the studied soils is given in Table. 5.

Table 5. Content of colloidal fraction in soddy-podzolic gleyey soils

Horizon	Depth, cm	Total, %	Including		Ratio organic/mineral
			Mineral, %	Organic, %	
			Virgin		
AY	3-10	2.0	1.44	0.56	0.38
ELg	10-20	1.5	1.10	0.40	0.36
BTg	30-40	4.1	3.79	0.31	0.08
Cg	120-130	6.0	5.92	0.08	0.01
			Arable		
P	0-30	2.5	2.15	0.35	0.16
BELg	40-50	7.6	7.32	0.28	0.03
BTg	70-80	7.6	7.42	0.18	0.02
Cg	130-140	7.5	7.43	0.07	0.01

The nature of the distribution of the colloidal fraction in the soil profile was determined by the course and development of the soil-forming process and is identical to the distribution of the silt fraction. The upper part of the profile of virgin forest soil is largely depleted of colloidal particles that is typical for the podzolic horizon. The composition of colloids throughout the profile is dominated by the mineral fraction. Organic colloids in the AY horizon account for 28% of colloidal particles. Down the profile, their absolute content gradually decreases. The distribution of mineral colloids in the profile of virgin soil has eluvial-illuvial nature.

The profile of arable drained soil is richer than its virgin analogue in terms of the total content of colloids (Table 5). The total amount of colloidal particles in the arable layer is 2.5%. Organic colloids account for 14% of the total content. This is 2 times less than their content in the AY horizon of virgin soil. Thus, the processes of removal of the organic part of colloidal particles when the soil is cultivated and drained are quite intense. According to Milyauskas (1963), in some periods of drainage runoff, the concentration of organic substances in it can reach 1.4 g l^{-1}.

At a depth of 40-50 cm, the total content of colloidal particles increased to 7.6% and changed little with depth. The composition of colloids is dominated by the mineral fraction. Just as in virgin soil, in arable soil the content of organic colloids decreases with depth. The destruction of the colloidal complex is developed in both soils, what is well confirmed by the removal-accumulation of colloidal particles in the profile of the compared soils (Table 6). This indicates that the prolonged cultivation led to an increase in the destruction and removal of colloidal particles. So, the total loss of colloids from the entire profile of virgin soil was 262.1 kg m^{-2}, while from the arable layer of drained soil, the losses amounted to 290.1 kg m^{-2}.

Table 6. Balance of the fraction < 0.0002 mm in soddy-podzolic soil

Horizon	Depth, cm	Bulk density, g cm^{-3}	fraction < 0,0002 mm		Removal-accumulation, g cm^{-3}	Sum of removal-accumulation, kg m^{-2}
			%	g cm^{-3}		
			Virgin			
AY	7	1.02	2.0	2.04	– 8.16	– 57.1
ELg	10	1.55	1.5	2.32	– 7.88	- 78.8
BTg	38	1.68	4.1	6.88	– 3.32	– 126.2
Cg	–	1.70	6.0	10.20	–	–
			Arable			
P	30	1.29	2.5	3.23	– 9.67	– 290.1
BELg	25	1.64	7.6	12.50	– 0.40	– 10.0
BTg	45	1.71	7.6	12.90	0	0
Cg	–	1.72	7.5	12.90	–	–

These data are confirmed by the reserves of colloidal fraction in 0-30 and 0-50 cm soil layers (Table 7).

Table 7. Reserves of colloids in virgin and arable soddy-podzolic soils, t ha^{-1}

Land	0-30 cm	0-50 cm	removal (–), accumulation (+) compared to an equal layer of the parent rock			
			0-30 cm	%	0-50 cm	%
Virgin	107.6	245.9	– 203.8	65.4	– 274.0	52.8
Arable	96.7	345.9	– 290.3	75.0	– 299.1	46.3

The absolute loss of colloidal particles from the 0-30 cm in virgin soil amounted to 203.8 *t* ha^{-1} and increased to 290.3 t ha^{-1} in arable dried soil. Losses from the 0-50 cm amounted to 274.0 and 299.1 t ha^{-1}, respectively. Consequently, prolonged agricultural use of clay glayey drained soil leads to increased destruction and removal of not only the silty fraction, but also colloidal particles outside the arable horizon.

That begs the question. What is the intensity of the process of removal of silty and colloidal fractions during cultivation and drainage? In all likelihood, these processes proceed quite vigorously. According to Motomura (1969), the removal of silt in the soils of this genesis during the laying of a closed drainage network proceeds "explosively". Already in the third year, the backfilling of the drains is silted. In addition, part of the silt settles in the drainage pipes, which reduces the lifetime of the drainage system. Obviously, the intensive destruction and removal of finely dispersed fractions from the eluvial stratum in solutions and suspensions during cultivation and drainage are irreversible consequences of agrogenesis.

Organoprofile

A characteristic feature of the humus profile of virgin soddy-podzolic glayey clay soil is the confinement of the maximum content of organic matter to the upper organogenic horizon and its sharp drop directly at the border of the transition of the grey-humus (AY) horizon to the eluvial (EL). In the AY horizon of virgin soil, the humus content is high - 4.9%. During the transition from the AY horizon to the EL horizon, the humus content decreases sharply to 0.9%. Down the profile, there is a further gradual decrease in the humus content (Table 8).

Table 8. Humus content in pre-colloidal and colloidal fractions of soddy-podzolic glayey soil, %

Horizon	Depth, cm	Content of humus, %	Particle size, mm	Content, %	From the weight of		From humus content
					Fraction	Initial soil	
			Virgin				
AY	3-10	4.90	0.001-0.0002	10.4	6.1	0.63	12.8
			<0.0002	2.00	28.5	0.56	11.6
ELg	10-20	0.90	0.001-0.0002	9.5	1.2	0.10	12.1
			<0.0002	1.50	11.3	0.16	18.4
BTg	30-40	0.40	0.001-0.0002	15.0	0.9	0.13	33.3
			<0.0002	4.10	5.8	0.23	59.3
Cg	120-130	0.25	0.001-0.0002	12.9	0.9	0.11	44.7
			<0.0002	6.00	1.1	0.06	28.7
			Arable				
P	0-30	3.36	0.001-0.0002	9.5	6.3	0.60	17.8
			<0.0002	2.5	14.7	0.36	10.9
BELg	40-50	0.60	0.001-0.0002	14.3	1.5	0.21	36.3
			<0.0002	7.6	1.9	0.15	24.6
BTg	70-80	0.24	0.001-0.0002	13.1	1.0	0.14	48.5
			<0.0002	7.6	1.2	0.14	33.7
Cg	130-140	0.22	0.001-0.0002	12.6	1.0	0.13	57.3
			<0.0002	78.5	1.1	0.08	37.4

The content of humus in the arable layer of cultivated soil is inferior to its content in the AY horizon of virgin soil. In the arable layer (layers 0-10; 10-20 and 20-30 cm), the distribution of humus is uniform. Fluctuations range from 3.31 to 3.4%. At a depth of 30-40 cm, at transition to the BEL horizon, the humus content decreases sharply to 0.6%. Consequently, in agrogenic soil, the general nature of the distribution of humus is preserved, but in the arable layer its content is much less than in virgin forest soil. The cultivation effect is manifested in the fact that in the process of operation a deep-humified agrohumic horizon (P) is created, which significantly exceeds in thickness the grey-humic horizon (AY) of virgin soil.

Thus, the agrogenic transformation of the organoprofile is manifested in an increase in the thickness of the humic layer and an increase in humus reserves in equally thick layers. In arable soil in 0-30 cm humus reserves were 130 t ha^{-1}, in 0-50 cm -149. 8 t ha^{-1}. In virgin soil in 0-30 cm - 56.4 t ha^{-1}, in 0-50 cm - 71.5 t ha^{-1}, respectively.

The content of humus in the pre-colloid fraction (Table 8) of the grey-humic horizon was 6.1% of the mass of the fraction, which is 12.8% of the total humus content in the soil. In the lower horizons of the profile the content of humus fixed by pre-colloids decreases and ranges from 1.2 to 0.9%. Humus, fixed by pre-colloid particles, accounts for 12.1% of the total soil content in the ELg horizon and 33.3% of the total soil content in the BTg horizon.

The absolute amount of humus bound to the colloidal fraction exceeds the content fixed by the pre-colloids. The revealed pattern is characteristic of all horizons of the virgin forest soil. The proportion of humus bound to colloidal particles from its total content in these horizons is 11.6% in the AY horizon, 18.4% in the EL horizon and 59.3% in the BTg horizon. Thus, with a decrease in particle size, their role in fixing organic matter in the sub-arable part of the profile increases.

The total contribution of finely dispersed particles (colloids and pre-colloids) in the binding of humus of virgin soil was: in the horizon AY - 24.4%, in the horizon ELg – 30.5 % and in the horizon BTg – 92.6 %. Therefore, the role of fine particles in the fixation of humus in virgin forest soil increases with depth (Table 8).

Long-term cultivation and drainage did not affect the absolute content of humus fixed on the surface of pre-colloid particles of arable soil. In the cultivated layer, its content was 6.3%, in the BEL horizon - 1.9% and in the BT horizon - 1.2% of the mass fraction, differing little from the content in corresponding horizons of virgin soil. However, the relative amount of humus recorded on the surface of pre-colloids, from its total content in agrogenic soil, increased and amounted to 17.8% in the arable layer and 36.3% in the BELg horizon, in comparison with virgin soil, i.e. increased by 1.4 and 3.0 times, respectively. The exception was the BTg horizon, where its content was lower than in the corresponding horizon of virgin soil. Thus, the relative contribution of pre-colloid particles in the fixation of humus during the cultivation of clay soil increases.

With a slightly higher content of colloidal fraction in the arable layer of cultivated soil, compared with the horizon AY of virgin soil (2.5 and 2.0%, respectively), the humus enrichment of colloids of arable soil was 2 times lower than in virgin soil (Table 8). However, the relative proportion of the participation of colloids of virgin and arable soil in the fixation of humus was the same (11.6 and 10.9%, respectively.

In the lower horizons of the profile, the absolute content of humus in the composition of colloids of arable soil decreases, and the share of participation in fixing the total humus of the soil increases. The total contribution of colloidal and pre-colloidal fractions in fixing humus in individual horizons of the profile was: P – 28.7, BELg – 60.9, BTg 82.2 %.

Thus, the total contribution of finely dispersed fractions (colloidal and pre-colloidal) in the fixation of humus in the arable layer was higher than in the grey-humic horizon of virgin soil.

Soddy-podzolic soils on band clays are one of the most difficult objects for land reclamation and agricultural use in the non-chernozem zone of Russia. In the 60-80 years, the soils of this genesis were a frequent object of drainage Motomura (1969). The necessity and economic feasibility of reclamation measures in connection with the high labor intensity and costs of cultivating and exploiting the soils of this genesis, their use for arable land has previously been repeatedly questioned (Karavaeva 1996; Motomura 1969; Pestryakov et al., 1979; Dyushofur 1970).

Drainage of soils on band clays certainly has some positive effect on the moisture regime and topping of these soils. However, the hydrological moisture regime of drained soils on strip clays is very unstable for agricultural production (Motomura 1969). In drained soils on band clays, the necessary hydrological effect can be achieved only if a special, rather complex and regularly carried out set of measures is performed, ensuring the organization and acceleration of surface runoff, and the discharge of intra-soil moisture by drainage lines. The positive impact on the water regime of these soils is achieved only as a result of simultaneous hydraulic engineering, agromeliorative and agronomic measures. Among them are regular, deep reclamation loosening (at least once in two years), carried out to a depth of 60-90 cm, surface agrotechnical loosening with light tools to a depth of 40-50 cm, cultivation measures. The higher the level of farming, the more profound changes the drained soils will undergo and the more favorable conditions are created for drainage operation.

Long-term land cultivation although it leads to a deep transformation of ecosystems, does not eliminate the possibility of their elimination after the cessation or weakening of the anthropogenic load (Tomasson 1972; Litvinovich 2009). Almost all the beneficial properties created by agrogenic exposure are reversible. The achieved level of fertility is a consequence of the level of anthropogenic impact (Litvinovich and Pavlova 2010). Given the high costs of re-cultivation and the duration of this process as well as the impossibility of full regulation of the water-air regime of the soils of this genesis without the re-draining, the economic feasibility of re-involvement into cultivation of these soils is not high.

According to Karavaeva (1996), with the directed cultivation of heavy clay soils on the band clays of the southern taiga of the North-West of Russia for a period of 20-25 years, it is possible to create only “semi-cultivated” arable soils. In the arable layer, despite the homogeneity and positive changes in a number of properties, unfavorable physical and water-physical properties are preserved or enhanced. In the sub-arable part (even during drainage), glayed horizons are preserved, which limits water movement. It is most expedient to use these soils for meadow and hay fields. It also seems appropriate to leave these habitats for the formation of forests on them.

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Agrogena evolucija humusno-podzolastog zemljišta: Mogućnost ponovnog uključivanja u obradu ugara formiranog na trakastim glinama

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Izvod

U Lenjingradskoj oblasti, severozapadna Rusija, proučavana je transformacija humusno-podzolastog glinovitog zemljišta u dugogodišnjoj poljoprivrednoj upotrebi (>200 god.). Ovom studijom izvodljivosti, ispitana je mogućnost rekultivacije ovih zemljišta nakon dugotrajnog nekorišćenja. Analizirana je morfološka struktura, granulometrijski sastav, sadržaj i odnos fero i oksidnih oblika gvožđa u profilu devičanskog (autohtone šume) i obradivog dreniranog zemljišta. Pored toga, u toku dugotrajne agrogeneze (> 200 god.) praćene su promene u organogenom profilu. U devičanskom zemljištu, tokom njegove pedogeneze, gubitak frakcija <0,01 mm iz eluvijalnog sloja bio je 877,4 kg m^{-2}, a gubitak frakcija <0,0001 mm bio je 287,5 kg m^{-2}, u poređenju sa matičnim supstratom koji nije zahvaćen procesima pedogeneze. Međutim, dugotrajna agrogeneza (>200 god.) dovela je do povećanog eluvijalnog gubitka sitnih čestica zemlje. Gubitak frakcije <0,01 mm iz obradivih horizonata iznosio je 1244,8, a frakcije <0,0001 mm iznosio je 570 kg m^{-2}. Ovo je posledica višegodišnje obrade zemljišta koja je povećala poroznost zemljišta i time intenzivirala ispiranje čestica gline, što je dovelo do povećanog ispiranja i eluvijalnih gubitaka. Ukupan gubitak koloida iz celog profila devičanskog zemljišta iznosio je 262,1 kg m^{-2}, a iz obradivog sloja dreniranog zemljišta - 290,1 kg m^{-2}. Humusno obogaćivanje koloida oranog (P) horizonta oranica bilo je dva puta niže od onog površinskog (AI) horizonta devičanskog zemljišta. Relativni udeo učešća koloida u fiksaciji humusa zemljištem je bio isti (11,6 i 10,9%,). U podpovršinskim horizontima, apsolutni sadržaj humusa u koloidima je smanjen, a udeo učešća u fiksaciji humusa povećan. Kada se humusno-podzolasto glinovito zemljište obrađuje, poboljšava se vodno-vazdušni režim, sadržaj i sastav humusa, povećava se dubina obradivog horizonta i smanjuje kiselost zemljišta. Istovremeno se ubrzava ispiranje finih zemljišnih materijala. Kada je ovo zemljište povučeno iz ratarske proizvodnje, pozitivne promene postignute kao rezultat obrade postepeno su se gubile. Po prvi put smo mogli da izračunamo gubitke finih frakcija zemljišta iz gornjeg sloja. Uzimajući u obzir visoke troškove rekultivacije ovog zemljišta i visoke troškove ponovnog postavljanja i održavanja optimalnog hidrološkog režima (drenažne mreže) zaključili smo da je ponovljeno oranje i uključivanje humusno-podzolastog glinovitog zemljišta u obradu ekonomski neopravdano.

Ključne reči: humusno-podzolasto glinovito zemljište, agrogena evolucija, fino disperzovana frakcija, organogeno-mineralni profil, koloidi

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