ISSN 1064-2293, Eurasian Soil Science, 2016, Vol. 49, No. 8, pp. 859–867. © Pleiades Publishing, Ltd., 2016.
Original Russian Text © M.F. Ovchinnikova, 2016, published in Pochvovedenie, 2016, No. 8, pp. 932–941.

Transformation of Humus Substances in the Long-Drained Surface-Gleyed Soddy-Podzolic Soils under Conditions of Pronounced Microrelief and Different Agrogenic Loads

M. F. Ovchinnikova

Educational and Experimental Soil-Ecological Center, Moscow State University, Moscow oblast, 141592 Russia
e-mail: biochem.ovchinnikova@yandex.ru

Received January 14, 2015

Abstract—The transformation of humus substances resulting from artificial drainage of the surface-gleyed soddy-podzolic soils under conditions of pronounced microtopography and different agrogenic loads was studied. The studied soil characteristics included acid–base conditions, the content and group composition of humus, the ratios between the fractions of humus acids, and optical density of humic acids. The features attesting to humus degradation were found in the soils of microdepressions periodically subjected to excessive surface moistening, in the soils of different landforms upon the construction of drainage trenches, and in the plowed non-fertilized soils. The response of humus characteristics to the changes in the ecological situation in the period of active application of agrochemicals for reclamation of the agrotechnogenically disturbed soils was traced. It was shown that the long-term dynamics of the particular parameters of the biological productivity of the soil depend on the hydrological and agrogenic factors, as well as on the weather conditions.

Keywords: soddy-podzolic soil (Albic Glossic Retisol), soddy-podzolic surface-gleyed soil (Albic Stagnic Glossic Retisol), humus transformation, drainage amelioration, humus degradation factors

DOI: 10.1134/S106422931608010X

INTRODUCTION

Construction of drainage systems in humid landscapes a purposeful action of agrotechnogenic nature, carried out in order to optimize the air-water regime in waterlogged soils of different genesis. Drainage amelioration is especially relevant for soils formed on heavy parent rocks with unfavorable hydrophysical properties inherited by soils. Intensification of the percolative water regime and, hence, stronger removal of fine particles, depletion of the upper part of the soil profile in exchangeable bases, and acidification, mostly pronounced in soils on acid and leached loamy and clay rocks, were observed in drained soils, together with positive consequences (optimization of hydrological, thermal, and redox regimes and activation of biological processes) [1, 3, 6, 9, 10, 22].

Such physical and physicochemical soil properties as composition and proportion of particle-size fractions, concentration and composition of exchangeable cations, and soil reaction are known as important factors of humification and are closely connected with the parameters of the humus system [16]. Unfortunately, there are few literature data about the effects and aftereffects of drainage amelioration. Moreover, the changes of humus characteristics recorded by different authors are ambiguous, possibly due to the differences in the methods of drainage and the properties of soils and parent rocks. The results of drainage are discussed in some works together with agricultural practices for fertility restoration of drained soil, and this makes it difficult to evaluate the real contribution of drainage to the changes of humus characteristics. Humus content as a rule decreased when drainage works were carried out without application of organic fertilizers or in the period before their application [1, 8, 13, 22, 26]. Agricultural use of drained soils with application of organic fertilizers promoted humus accumulation, and this was observed mostly within the plow layer [3, 8, 22].

The direction and depth of the changes in the composition and properties of humus substances and molecular structures of humic acids in drained soil are determined greatly by the degree of "dilution" of the upper part of the soil profile with the material of the lower layers and by its properties [11, 14].

Insufficient available information, unfortunately, does not allow characterizing in details the features of the changes in humus characteristics when draining different soils on different parent rocks, taking into consideration any other factors than drainage. The problem of preservation the fertility of ameliorated soils and their active agricultural use under the conditions of recent unbalanced agriculture remains relevant, but poorly studied.

The task of this work is to study the transformation of humus substances in soddy-podzolic soils in the case of prolonged drainage under the conditions of pronounced microrelief and different agrogenic loads, and to assess the results of changes in humus characteristics relative to soil productivity.

OBJECTS AND METHODS

The study was carried out on soddy-podzolic loamy soils of production field, Educational and Experimental Soil-ecological Center, Moscow State University (Moscow oblast). The parent rock was represented by mantle loams on moraine deposits. Soil cover of the field was characterized by small-pattern and mosaic character caused by the prominent microrelief. The total area of the field was 12 ha, of which approximately 1/3 was composed of microdepressions in the form of shallow hollows with a specific surface-flowing moistening against the background of percolative water regime. Soil cover of microhighs was presented by soddy-podzolic soils (Albic Glossic Retisols (Abruptic, Aric)) typical for automorphic landscapes of southern taiga subzone (Ap–A2–B1–B2). Soddy-podzolic surface-gley soils (Albic Stagnic Glossic Retisols (Abruptic, Aric)) formed in the lower landscape positions subjected to periodical surface water-logging in the time of snow melt or long-lasting rains in summer and autumn with characteristic signs of gleyzation (Apg–A2g–B1g–B2g). The morphological profile of surface-gley soils was characterized by bluish and rusty mottles in all horizons, humus mobility, abundance of Fe–Mn concretions, and a more pronounced podzolic horizon. The drainage system in the form of subsurface tile drainage was constructed all over the field in 1987. Drains 7.5 cm in diameter were placed at the depth of 0.8–0.9 m with spacing of 15 to 20 m. The field was used in the systems of four-field grain–grass–row-crop rotation up to 1996. Peat-manure compost was applied under the row crop at the rate of 40 t/ha in 1989; liming was carried out in 1989 and 1990 (at the rate of 1 and 0.5 hydrolytic acidity). The rates of mineral fertilizers were calculated according to the demands of agricultural crops: N260P90K270 in 1988–1992. Agricultural chemicals were not used since 1993. The field was taken out of the crop rotation system in 1997 and was occupied by legume-grass mixtures up to now. Agricultural impact in this period was connected with the periodical tillage operations (plowing, disk harrowing, and cultivation), grass mowing, and sowing of perennial grasses.

Soil samples were taken in June on microhighs and microlows from the depths of 0–20 and 20–40 cm in fivefold for every component of the relief. The samples were taken before the drainage amelioration (1987), one year after drain ditching (1988), and then at five-year intervals (1992, 1997, 2002, 2007, 2012). Humus content, pH of salt extract, hydrolytic acidity, and exchangeable calcium and magnesium were determined in soil samples with routine methods [21]; group and fraction composition of humus was determined by Tyurin's method in modification by Ponomareva and Plotnikova [20]; optical density of the fractions of humic acids was also determined [19]. Humus composition and properties of humic acids were assessed according to the improved system of humus status parameters [18]. Parameters of the intensity of humic acid neoformation and humate formation were calculated by the results of analysis of the humic acid composition. Soil bioproductivity was evaluated in the years of legume-grass mixture cultivation by 1 m^2 sampling plot [7].

Statistical analysis of the results was carried out with the methods of variance, dispersion, and correlation analyses [7].

RESULTS AND DISCUSSION

Parameters of the soil cation exchange complex (CEC) and humus contents. The changes of the parameters of soil chemical properties is the integrated reflection of the effects of different factors with periodical strengthening or weakening of the effects of particular factors. The influence of microrelief with different degrees of manifestation was observed up to the end of the observation period. Maximal contrast range of parameters in soils of different relief components was found in the period before the performance of drainage work (1987). The increase of hydrolytic acidity (by 18–21%), decrease of the sum of exchangeable bases (by 24–30%), and 1.5–2-fold decrease of humus content were recorded, along with well-defined signs of gleyzation in soils of microdepressions in comparison with their automorphic analogs (Table 1). Acidity increase and dehumification are the characteristic features of different hydromorphic soils [2, 5, 12]. Drainage contributed to optimization of the hydrological regime and decrease of contrasting parameters, but conditions more favorable for humification in soils of microhighs remained practically until the end of study period.

The disturbance of soil cover in the course of constructing the drainage system deteriorated soil chemical properties in all components of the relief (1988). The increase of acidity parameters (by 9–21%) and decrease of the sum of exchangeable bases (by 9–25%) and humus content (by 11–20%) were observed within the 40-cm layer of both soil varieties. Active application of lime and organic and mineral fertilizers in 1989–1992 promoted restoring of chemical properties of agrotechnogenically disturbed soils. The return of CEC parameters to their initial values (in some cases exceeding these values) was observed in 5 years after draining. Humus content in the plow layer of both soil varieties returned to its initial level by this time, but it was lower in the plowpan.

Table 1. Chemical properties of soddy-podzolic soils depending on the duration of drainage, microrelief (numerator—microhighs, denominator—microlows), and agrogenic loads

Duration of drainage, years	Depth, cm	Humus, %	pH_{KCl}	Ac tot*	Ca^{2+}	Mg^{2+}	Ca^{2+}+Mg^{2+}
				cmol(+)/kg			
Crop rotation with application of agricultural chemicals							
0 (before drainage)	0–20	4.27/2.79	6.2/6.0	1.6/1.9	11.6/8.4	4.5/2.8	16.1/11.2
	20–40	3.39/1.69	6.0/5.7	1.9/2.3	10.3/7.1	3.8/3.5	14.1/10.6
1	0–20	3.77/2.46	5.6/5.4	1.9/2.3	9.6/8.3	3.7/2.0	13.3/10.3
	20–40	3.02/1.36	5.6/5.1	2.3/2.5	7.8/7.6	2.8/1.6	10.6/9.2
5	0–20	4.38/2.78	6.8/6.3	1.2/1.4	11.4/10.8	5.3/4.5	16.7/15.3
	20–40	3.12/1.45	6.2/6.0	1.4/2.1	9.8/9.4	4.3/3.7	14.1/13.1
Crop rotation without application of agricultural chemicals							
10	0–20	4.14/2.81	6.6/6.4	1.4/1.5	10.0/9.8	4.0/4.2	14.0/14.0
	20–40	2.92/1.80	6.5/6.2	1.5/1.8	9.1/8.5	4.6/4.0	13.7/12.5
Withdrawal of the field from crop rotation, growing of grass mixture							
15	0–20	3.97/3.00	6.7/6.2	1.5/1.5	12.1/9.5	6.1/4.5	18.2/14.9
	20–40	2.70/2.08	6.6/6.0	1.6/1.7	9.0/9.2	5.3/4.6	14.3/13.8
20	0–20	3.86/2.80	6.5/6.0	1.6/1.7	11.0/9.6	6.0/5.4	17.0/15.0
	20–40	2.60/2.11	6.4/5.8	1.7/2.0	9.2/9.0	5.9/5.0	15.1/14.0
25	0–20	3.73/2.98	6.4/5.8	1.7/1.9	11.2/10.5	6.6/5.5	17.8/16.0
	20–40	2.51/2.05	6.4/5.7	1.9/2.2	10.0/10.0	5.7/5.1	15.7/15.1
LSD_{05}	0–20	0.21/0.14	0.3/0.3	0.2/0.3	–	–	1.5/1.8
	20–40	0.25/0.23	0.3/0.3	0.2/0.3	–	–	1.3/1.7

* Ac tot—Total (hydrolytic) acidity.

There was no expressed regularity in the changes of the soil acid-base status in the period of field use in crop rotation without application of agricultural chemicals (1993–1997). The changes in humus content over this period were observed as the trend towards its decrease in soils of microhighs and increase in soils of microlows.

Acidification (or the trend towards acidification) was most clearly manifested in the changes of hydrolytic acidity parameters; it was observed within the

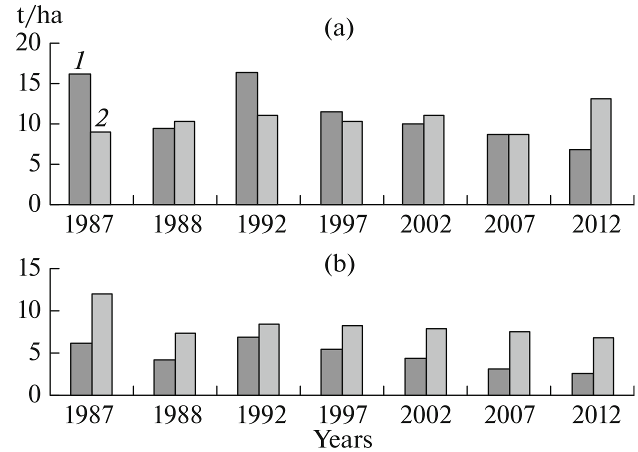

Fig. 1. The pools of (*1*) humates and (*2*) fulvates in the upper soil layer (0–40 cm) of (a) microhighs and (b) microlows under the impact of drainage and agrogenic loads.

40-cm soil layer irrespective of the relief over the 15-year-long period of cultivating the legume-grass mixture without agricultural chemical application (1997–2012). An increase in CEC in both soil varieties recorded over the same period was presumably explained by the positive effect of long-lasting cultivation of legume–grass mixture restricting the removal of exchangeable cations and contributing to the increase of their biological accumulation by root system of plants [4]. The former trend in the changes of humus content was preserved: humus content decreased over 15 years by 10 and 14% in the plow layer and plowpan on the microhighs; it increased by 6 and 14% in the same soil layers of microlows, presumably due to lesser effect of tillage operations in spring.

Fractional and group composition of humus. The change of humification conditions under different effects was adequately reflected in some qualitative humus characteristics. The signs of degradation humus were recorded in the soils of microdepressions subjected periodically to the effect of excessive surface moistening. The most pronounced manifestation of the adverse effect of the hydrological factor was observed in the podzolic horizon of non-drained soil, where a 2.7-fold decrease of total content of humic acids HA (% of Corg), 2.5-fold weakening of humic acid formation, 4.1-fold weakening of the process of humate formation, and replacements of the fulvate-humate humus type by the strongly fulvate type were observed (Tables 2 and 3). Although the contrast in soil properties between the different relief components was mitigated after drainage, the advantage of humus quality by many parameters remained obvious in microhigh soils.

The signs of humus quality degradation connected with soil cover disturbance in the course of drain ditching were manifested in the decrease of humification degree and unfavorable change of humus type. Adverse changes of humus quality were clearly observed within the 40-cm-thick layer of soil in elevated sites and mostly in the plow layer of soil in microdepressions. The intensity of adverse effect of the agrotechnogenic factor on the qualitative humus characteristics within plow layer was comparable with the effect of excessive surface moistening before draining was performed.

Restoration of humus characteristics was recorded in most cases 5 years after drain ditching due to active application of agricultural chemicals (lime and organic and mineral fertilizers) and two years of grass growing (Tables 2, 3). Application of organic fertilizers mostly promoted the activation of humic acid neoformation and the increase of the relative portion of the first fraction in humic acids. Liming affected most significantly the content of humic acids of the second fraction: humates and fulvates. Primary formation of humates induced by liming was observed under optimal conditions for humification typical for automorphic soils; primary fulvate formation was observed under unfavorable conditions for humification typical for negative landforms. Humates dominated the composition of humic acids of the second fraction in the 40-cm-thick layer of soil in microhighs before the performance of drainage construction (1987) and during some time after liming (1992, 1997); subsequently, a gradual decrease of the relative portion of humates and the increase of the portion of fulvates was observed as agrogenic effects grew weak. Fulvates dominated the composition of humus acids of the second fraction in the soil profile of microdepressions during 25 years of observation (Fig. 1).

The deterioration of the humus characteristics restored after drainage works was observed when the field was used without application of agricultural chemicals (from 1993 to 2012). Unfavorable trends in the humification process and degradation of humus quality at the group level of humus substances were characterized by the decrease of humification degree with unfavorable replacement of humus type, and at the level of the fractions of humic acids by the weakening of both stages of humification and the decrease in the quantity of agriculturally valuable fractions HA1 and HA2. The 1.5–3.2-fold weakening of the process of HA formation and 1.4–1.7-fold decrease of HA1 content, as well as a 2.2–2.9-fold weakening of the process of humate formation and 1.9–3.0-fold decrease of humate content, were recorded within the 40-cm-thick layer of automorphic soil and in plow layer of soil in microdepressions during 20 years. Weakening of both stages of humification and humate destruction were clearly observed in the plow pan of soil in microdepressions against the background of an increase in the content of humus and insignificant changes in the humus group composition.

Table 2. Group composition of humus in soddy-podzolic soils depending on the duration of drainage, microrelief (numerator—microhighs, denominator—microlows), and agrogenic loads

Duration of drainage, years	Depth, cm	Corg, %	Cha	Cfa	Cnh	Cha	Cfa	Cnh	Cha/Cfa
			% of soil			% of Corg			
Crop rotation with application of agricultural chemicals									
0 (before drainage)	0–20	2.47/1.62	1.19/0.62	0.72/0.61	0.56/0.39	48.0/38.4	29.3/37.5	22.7/24.1	1.64/1.02
	20–40	1.97/0.98	0.89/0.16	0.63/0.44	0.46/0.37	45.1/16.7	31.8/45.3	23.1/38.0	1.42/0.37
1	0–20	2.10/1.43	0.76/0.44	0.75/0.57	0.59/0.42	36.3/30.9	35.5/39.9	28.2/29.3	1.02/0.77
	20–40	1.75/0.79	0.51/0.11	0.64/0.31	0.60/0.37	29.2/14.5	36.5/39.1	34.3/46.4	0.80/0.37
5	0–20	2.54/1.61	1.28/0.58	0.76/0.55	0.50/0.47	50.2/36.1	30.0/34.4	19.8/29.5	1.67/1.05
	20–40	1.81/0.84	0.81/0.21	0.56/0.32	0.43/0.31	45.0/25.4	31.1/37.9	23.9/36.7	1.45/0.67
Crop rotation without application of agricultural chemicals									
10	0–20	2.40/1.63	0.83/0.52	0.72/0.59	0.84/0.65	34.5/32.0	30.3/35.9	35.2/39.8	1.14/0.89
	20–40	1.69/1.04	0.56/0.25	0.56/0.37	0.59/0.42	33.1/23.8	33.0/35.4	34.9/40.8	1.00/0.67
Withdrawal of the filed from crop rotation; growing of grass mixture									
15	0–20	2.30/1.74	0.71/0.50	0.76/0.59	0.83/0.65	31.0/29.0	33.0/33.7	36.0/37.3	0.94/0.86
	20–40	1.57/1.21	0.47/0.28	0.50/0.43	0.60/0.51	30.1/22.9	31.7/35.2	38.2/41.9	0.95/0.65
20	0–20	2.24/1.62	0.72/0.41	0.71/0.59	0.82/0.62	32.0/25.5	31.6/36.4	36.4/38.1	1.01/0.70
	20–40	1.51/1.22	0.43/0.28	0.53/0.47	0.55/0.47	28.3/23.0	35.4/38.3	36.3/38.7	0.80/0.60
25	0–20	2.16/1.73	0.62/0.39	0.73/0.69	0.81/0.65	28.5/22.8	34.0/39.8	37.5/37.4	0.84/0.57
	20–40	1.46/1.19	0.39/0.27	0.60/0.49	0.47/0.43	26.6/22.4	41.1/41.5	32.3/36.1	0.65/0.54
LSD_{05}	0–20	0.12/0.08	0.19/0.11	0.02/0.04	0.12/0.10	5.3/4.3	2.1/2.0	5.8/5.3	0.21/0.10
	20–40	0.15/0.13	0.17/0.06	0.02/0.06	0.05/0.06	6.4/3.1	2.9/3.0	4.9/2.8	0.18/0.11

Optical density of the fractions of humic acids. The changes of optical density parameters characterizing the structural features of HA were less significant during 25 years of observation than the changes of qualitative characteristics of HA (Table 4). The values of long-term variations in concentrations of different HA fractions ranged within 24–43% and those of optical density within 9–15%.

Some authors identified the relationship of optical parameters of HA different in origin and concentrations with the proportion between the structures different in their degree of condensation, molecular

Table 3. Intensity of the process of humic acid new formation (Cha1/Cfa1) and humate formation (Cha2/Cfa2) depending on time of drying, specificity of microrelief, and agrogenic load (above the line, soils of microhigh; under the line, soils of microlows)

Depth, cm	Time of drying, years							LSD_{05}
	0	1	5	10	15	20	25	
	4-field crop rotation				legume-grass mixture without a			
	with a*			without a*				
	Cha1/Cfa1							
0–20	2.32/1.51	1.33/1.08	2.24/2.21	1.23/1.19	1.12/0.90	1.40/0.87	1.51/0.70	0.28/0.28
20–40	1.91/0.76	1.03/0.57	1.95/1.81	1.20/1.21	1.30/1.24	1.04/1.08	0.97/0.92	0.24/0.24
	Cha2/Cfa2							
0–20	2.01/0.61	0.86/0.62	1.67/0.98	1.14/0.78	0.93/0.70	0.79/0.50	0.60/0.45	0.30/0.15
20–40	1.57/0.38	0.96/0.49	1.26/0.57	1.32/0.30	0.86/0.34	0.62/0.29	0.43/0.24	0.24/0.11

*a—Agricultural chemicals.

weight, and optical density [23–25, 27–30]. The HA fractions of podzolic soils under study were characterized by low and very low values of optical density, and this fact suggested their simplified structure. Minimal values of optical density (E_c 3.5–5.1) were typical for HA3, composition of which was dominated by the long-chain aliphatic structures with high molecular weight (70–100 kDa and more) and low optical density [17]. The increase of optical density of HA2 by 2–3 times (up to 7.3–10.5) in comparison with HA3 was related to the increase of a relative portion of more optically dense medium-molecular aromatic structures. HA1 were close to HA2 in terms of proportion between the structures with different molecular weight and optical density values [17].

The changes in optical density of HA fractions were ambiguous in different periods of observation; the degree and direction of changes were significantly determined by the structural features of HA fractions, strength of their bonds with mineral components, and the character of impacts.

More pronounced response to the changes in the environment caused by different factors was observed for HA1 and HA2 fractions that actively participated in metabolic biochemical processes. Maximal sensitivity to the influence of excessive surface moistening was recorded in HA1. The E_c parameters of HA1 in soil of microdepressions were inferior to corresponding parameters of automorphic soil at most observation dates. Most pronounced was the adverse effect of hydrological factor prior to drainage amelioration. The decrease of E_c HA1 by 9–24% in comparison with that in the soil of the microhigh was recorded in this period, and this indicated the destruction of both aliphatic and aromatic structures. Significant increase of E_c HA2 (by 15–17%) in this period attested to the predominant destruction of peripheral structures of aliphatic nature.

The direction of the changes in optical density parameters of HA fractions (increase of E_c HA1 and HA2 and decrease of E_c HA3) a year after drainage construction (1988) was determined by the character of profile distribution of parameters in the initial soil, and this confirmed the mechanical nature of agrotechnogenic impact.

The changes of E_c HA1 and HA2 in the periods with different agrogenic loads were determined mostly by the intensity of corresponding stages of humification process. A significant decrease of E_c HA1 (by 13–26%) and HA2 (by 22–32%) was the result of enrichment of HA with high-molecular and less optically dense components owing to application of agricultural chemicals (1989–1992), activation of new formation of HA, and humate formation in the 40-cm soil layer in different components of the relief. A trend was observed towards some increase of E_c HA value under the conditions of slowing of both stages of humification and intensification of the processes of organic matter mineralization (when agricultural chemicals were not applied). Similar patterns were observed in particular dates of the study during long cultivation of grass mixtures. Inverse correlation (from medium to strong) between E_c HA1 value and the intensity of the first stage of humification ($r = -0.65, -0.31$) and E_c HA2 value and the intensity of the second stage of

Table 4. Composition and optical density of humic acid fractions (above the line, soils of microhighs; under the line, soils of microlows)

Time of drying, years	Depth, cm	HA fractions, % of Corg				$E_c^{mg/mL}$		
		1	2	3	sum total	HA1	HA2	HA3
Crop rotation with application of agricultural chemicals								
0	0–20	21.6/17.5	14.3/9.2	12.1/11.7	48.0/38.4	7.5/6.8	9.0/10.5	4.2/4.1
	20–40	18.6/4.6	13.5/8.5	13.0/3.5	45.1/16.7	7.5/5.7	9.5/10.9	4.4/5.0
1	0–20	16.4/12.8	9.6/7.3	10.3/10.8	36.3/30.9	8.6/7.5	10.5/10.2	3.5/3.6
	20–40	11.7/3.1	8.6/6.7	8.9/4.7	29.2/14.5	9.3/6.9	10.3/11.1	3.7/4.3
5	0–20	19.3/16.8	15.6/11.7	15.3/7.6	50.2/36.1	7.0/6.4	7.9/8.0	3.7/4.0
	20–40	19.1/11.4	12.9/8.4	13.0/5.6	45.0/25.4	6.9/6.0	7.3/7.5	3.6/4.2
Crop rotation without application of agricultural chemicals								
10	0–20	13.5/9.5	12.0/9.3	9.0/13.2	34.5/32.0	7.1/6.8	8.3/8.0	4.0/4.2
	20–40	15.0/10.3	8.6/5.0	6.5/8.5	33.1/23.8	7.0/6.5	8.1/7.8	4.2/4.5
Withdrawal of the field from crop rotation; growing of grass mixture								
15	0–20	14.0/12.0	10.5/6.8	6.5/10.2	31.0/29.0	7.5/6.9	8.1/7.9	4.2/4.4
	20–40	14.3/13.0	9.0/3.7	4.4/6.2	30.1/22.9	7.3/6.4	8.3/7.6	4.1/4.0
20	0–20	12.5/13.0	9.5/5.0	10.0/7.5	32.0/25.5	6.5/6.3	8.6/7.3	3.9/4.4
	20–40	14.5/15.7	7.8/3.0	6.0/4.3	28.3/23.0	6.3/6.0	8.0/7.9	4.3/4.7
25	0–20	11.0/11.3	8.3/3.9	9.2/7.6	28.5/22.8	6.2/6.3	8.8/8.6	4.5/4.7
	20–40	13.8/14.5	5.8/2.2	7.0/5.7	26.6/22.4	5.9/5.3	8.3/8.2	5.0/5.1
LSD_{05}	0–20	2.2/1.7	1.8/2.2	1.5/1.3	5.3/4.3	0.4/0.3	0.5/0.7	0.2/0.2
	20–40	1.5/3.2	1.8/2.1	2.0/1.4	6.1/3.1	0.6/0.4	0.6/0.8	0.3/0.2

humification (r = –0.91; –0.56) was found for the plow layer of soil in elevated and lower sites in the period of active application of agricultural chemicals in crop rotation. Such relationship between the parameters was not observed over the whole period of observation because of ambiguous character of their changes depending on a particular environmental situation.

Generally, the decrease (or the trend towards the decrease) of E_c HA1 and HA2 values was recorded over the 25-year period of observations in the 40-cm-

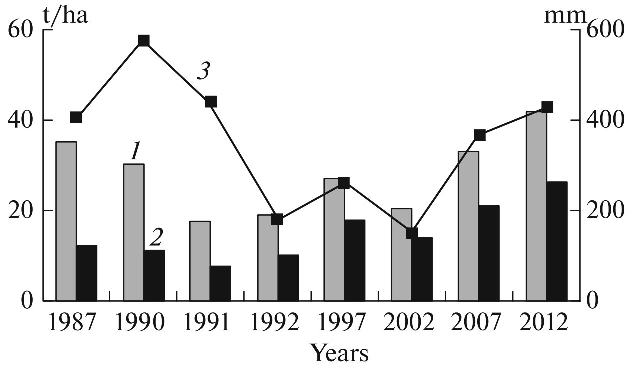

Fig. 2. Yields of the green mass of herb mixtures during the 25-year-long period after drainage of the surface-gleyed soddy-podzolic soil: (*1*) microhighs, (*2*) microlows, and (*3*) precipitation in May–September.

thick layer of the reclaimed soil relative to the initial level before amelioration, and this was one of the signs of simplification of their structure and the decrease of agriculturally valuable properties. The most pronounced decrease of E_c HA1 (from 7.5 to 5.9–6.2) characterized the soils of microhighs; the decrease of E_c HA2 (from 10.5–10.9 to 8.2–8.6) characterized the soils of microlows, and this basically corresponded to the scale of destruction of these fractions over 25 years. A similar trend in the changes in optical density of HA1 and HA2 was observed in soddy-podzolic gleyed sandy soil after withdrawing the land from agriculture and 20 years of being under natural herbaceous vegetation [15].

As for E_c HA3, insignificant increase (or the trend towards the increase) in comparison with the initial level was recorded over the 25-year-long period of observations. The long-term dynamics of E_c HA3 had no explicit regularity.

Biological productivity of the soil. The impacts of different factors were clearly expressed in the character of long-term dynamics of the parameters of soil bioproductivity, which were assessed in the years of grass mixture cultivation by the yield of their herbage. The most pronounced adverse effect of excessive surface moistening was observed before drainage construction in 1987: herbage yield of grass mixture in depressions was 2.9 times lower than that of soil on elevated sites (Fig. 2). The degrease of grass yield all over the field (mostly on elevated sites) 3–4 years after the performance of drainage work (1990, 1991) was the result of negative changes in the parameters of soil fertility and of extremely low precipitation in 1992. Maximal yield exceeding the level before amelioration was recorded in both soils in 2012, when the amount of precipitation over the growing period was 1.4 times higher than the normal annual precipitation. A pronounced decrease of contrast between the relief components in bioproductivity was observed in the period of grass cultivation, but the advantage of soils on the elevated sites remained up to the end of the period of observations (LSD_{05} = 2.98 t/ha).

CONCLUSIONS

The transformation of humus substances during long agricultural use of ameliorated soddy-podzolic and surface gleyed soddy-podzolic soil were characterized taking into consideration different types of factors: hydrological, agrotechnogenic, and agrogenic. The signs of degradational transformation of humus substances were recorded under the influence of hydrological and agrotechnogenic factors and in the periods of field use without application of agricultural chemicals. The unfavorable effect of hydrological factor manifested itself mostly before drainage amelioration and was preserved more or less until the end of observation period, despite the optimization of moisture regime after amelioration. The signs of agrotechnogenic humus degradation caused by the disturbance of the soil cover in the course of drainage ditching were characterized a year after drainage construction (before the application of the set of agricultural measures); more pronounced manifestation of these signs was observed in soils of microhighs. The weakening of humification processes and deterioration of humus characteristics were observed in both cases despite different nature of the factors and different mechanisms of degradation.

Application of the system of agricultural measures in order to reclaim the agrotechnogenically disturbed soils promoted activation of both humification stages and restoration of most humus characteristics up to the initial (before the amelioration) level. The deterioration of humus properties restored after amelioration was observed when agricultural chemicals were not applied: it occurred quickly in the period of intense use of plowed field and slowly in the period of long-lasting use of the perennial grasses.

It should be noted that most pronounced evidences of degradational changes of humus characteristics over the 25-year-long period of agricultural use of reclaimed soddy-podzolic soils (last 20 years without application of chemicals) were observed within the 40-cm layer of soils on microhighs, where the 1.5–2-fold decrease of the intensity of HA new formation process, 3.4–3.7-fold weakening of the complication process of humus structures, decrease of the content in humus of agriculturally valuable fractions HA1 and HA2, simplification of their structures, replacement of humate and fulvate-humate type of humus by the fulvate one, and the decrease of total humus content were recorded. Less pronounced changes of humus characteristics of the same direction in the soil of microdepressions were observed mostly within the plow layer.

The changes of humus properties under the influence of different factors and the effect of weather conditions (and first of all of rainfall) were reflected in the character of long-term dynamics of soil bioproductivity, which was evaluated in the years of growing the grass mixtures by their herbage yield.

REFERENCES

1. T. N. Azarenok, "Changes in the composition and properties of peat bog soils affected under the impact of drainage reclamation," in *Proc. of the Conference "Methods for Improving Soil Fertility, Fertilizer Efficiency, and Plant-Protective Means"* (Gorki, Belarus, 2003), pp. 7–10.
2. A. B. Akhtyrtsev, "Influence of surface gleyzation on the humus content in forest-steppe soils," Pochvovedenie, No. **4**, 17–23 (1985).
3. V. A. Bol'shakov, L. P. Orlova, M. S. Simakova, N. A. Muromtsev, Z. N. Kakhnovich, and I. V. Reznikov, "The impact of drainage and agrotechnologies on the chemical properties of gleyic soddy-podzolic soils and drainage and soil waters," Pochvovedenie, No. **4**, 438–445 (1995).
4. A. S. Vladychenskii and V. M. Telesnina, "A comparative characterization of postagrogenic soils under different lithological conditions in the southern taiga," Moscow Univ. Soil Sci. Bull. **62** (4), pp 167–174 (2007).
5. V. P. Vlasenko, "Development of hydromorphism in soils of agrolandscapes in the depressions of Western Ciscaucasia," Eurasian Soil Sci. **42** (5), 488–495 (2009).
6. E. I. Gagarina and N. N. Matinyan, "Chemical and mineralogical composition of clay fractions in drained soils on varved clay," Pochvovedenie, No. **3**, 55–63 (1993).
7. B. A. Dospekhov, *Field Experiments with the Principles of Statistical Treatment of Data* (Al'yans, Moscow, 2011) [in Russian].
8. I. M. Emel'yanova and N. E. Basharina, "Changes in the contents and qualitative composition of humus of in reclaimed soils under the impact of fertilizers," Pochvovedenie, No. **4**, 133–136 (1989).
9. F. R. Zaidel'man, "Hydrological factor of anthropogenic degradation of soils and the methods of its control," Eurasian Soil Sci. **33** (10), 1118–1128 (2000).
10. F. R. Zaidel'man, "Hydromorphic soils: genesis, melioration, and ecology," in *Plenary Reports on the All-Russia Scientific Conference* (Moscow, 2002), pp. 3–20.
11. F. R. Zaidel'man and I. V. Kovalev, "Humus of light gray gley soils and its change caused by bogging and drainage," Vestn. Mosk. Univ., Ser. 17: Pochvoved., No. 4, 27–35 (1994).
12. F. R. Zaidel'man, A. S. Nikiforova, L. V. Stepantsova, T. V. Krasina, and V. N. Krasin, "Ecological-hydrological and genetic features of the soils of the Tambov Plain," Eurasian Soil Sci. **47** (4), 223–235 (2014). doi doi 10.1134/S1064229314040115
13. V. V. Kanev and V.G. Kazakov, "Transformation of the properties of soddy-podzolic soils under the impact of drainage and cultivation," Eurasian Soil Sci. **38** (6), 664–675 (2005).
14. N. O. Kovaleva and I. V. Kovalev, "Specific features of organic matter of iron-manganese concretions in grey forest soils according to C^{13} NMR spectroscopy," Vestn. Mosk. Univ., Ser. 17: Pochvoved., No. 2, 23–31 (2003).
15. A. V. Litvinovich and O. Yu. Pavlova, "Changes in the humus status of a layland sandy gleyic soddy-podzolic soil," Eurasian Soil Sci. **40** (11), 1181–1186 (2007).
16. M. F. Ovchinnikova, *Humus Degradation under Different Environmental Conditions* (Tvorcheskii Litsei, Moscow, 2012) [in Russian].
17. M. F. Ovchinnikova, "Features of natural stability and agrogenic transformation of soil humus," Eurasian Soil Sci. **46** (12), 1150–1163 (2013).
18. D. S. Orlov, O. N. Biryukova, and M. S. Rozanova, "Revised system of the humus status parameters of soils and their genetic horizons," Eurasian Soil Sci. **37** (8), 798–805 (2004).
19. T. A. Plotnikova and N. E. Orlova, "Application of a modified Ponomareva–Plotnikova method for determination of the composition, nature, and properties of soil humus," Pochvovedenie, No. **8**, 120–130 (1984).
20. V. V. Ponomareva and T. A. Plotnikova, *Humus and Soil Formation* (Nauka, Leningrad, 1980) [in Russian].
21. *Practicum on Agrochemistry* (Mosk. Gos. Univ., Moscow, 2001) [in Russian].
22. M. S. Simakova and V. Yu. Gel'tser, "Changes in the properties of gleyed loamy soddy-podzolic soils after drainage," Pochvovedenie, No. **8**, 97–107 (1992).
23. O. A. Trubetskoi and O. E. Trubetskaya, "^{13}C-NMR analysis of components of chernozem humic acids and their fractions with different molecular sizes and electrophoretic mobilities," Eurasian Soil Sci. **44** (3), 281–285 (2011).
24. O. E. Trubetskaya, O. A. Trubetskoi, B. A. Borisov, and N. F. Ganzhara, "Electrophoresis and size-exclusion chromatography of humic substances extracted from detritus and soils of different geneses," Eurasian Soil Sci. **41** (2), 171–175 (2008).
25. O. A. Trubetskoi, O. E. Trubetskaia, O. I. Reznikova, and G. V. Afanas'eva, "Weight distribution and optical properties of soil humic acids fractionated by gel chromatography coupled by electrophoresis," Biol. Bull. **27** (1), 71–75 (2000).
26. T. I. Khokhlova, "Properties of soils and soil covers in reclaimed moraine ridges," in *Genetic Features of Drainage of Gleyed Soils in the Nonchernozemic Zone and Their Evolution* (Dokuchaev Soil Science Institute, Moscow, 1992), pp. 123–133.
27. A. Piccolo, "The supramolecular structure of humic substances," Soil Sci. **166** (11), 810–832 (2001).
28. A. Piccolo, P. Conte, and A. Cozzolino, "Chromatographic and spectrophotometric properties of dissolved humic substances compared with macromolecular polymers," Soil Sci. **166** (3), 174–185 (2001).
29. M. Simon, J. Garcia, C. Gil, and A. Polo, "Characteristics of the organic matter of Mediterranean high-mountain soils," Geoderma **61** (1/2), 119–131 (1994).
30. K. Tsutsuki and S. Kuwatsuka, "Molecular size distribution of humic acids as affected by the ionic strength and the degree of humification," Soil Sci. Plant Nutr. **30** (2), 151–162 (1984).

Translated by T. Chicheva