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Variants of post-agrogenic soil reproduction in agrolandscapes (A case study in Belgorod region)

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Abstract. The main variants of natural reproduction of soils in agricultural landscapes in the fallow regime are considered in the article. As an example, the soils are presented, the reproduction of which occurs on the soils destroyed by erosion or technogenic abrasion, as well as on anthropogenic mounds. Background agrosoils are clay-illuvial Chernozems, moderately eroded and severely eroded, which are presented for comparison. The variant of the applicative (postagrogenic) reproduction of soils with the superposition of the regeneration profile on the residual profile of the degraded precursor soil, as well as the variant of the recent (quasi-primary) reproduction on the soil and subsoil with a disintegrated matrix (mounds of anti-erosion dikes) are distinguished. Intermediate situations are possible between these basic variants. In case of applicative reproduction, the rate of the morphological organization of the regeneration profile is higher than at the recent one, but the composition of the organic matter of the postagrogenic horizon has the features of “inheritance” from the plough horizon.

1. Introduction

The transition of agrogenically degraded soils to the state of fallow causes a change in the regime of pedogenesis in them, which is generally described as an expanded reproduction of morphological and functional properties. The study of the regularities of this process makes it possible to expand the understanding of self-development (ontogeny) of soils under different states of the zero-moment. Thus, to describe the postagrogenic dynamics of soils, it will be productive to distinguish the secondary reproduction, i.e. regeneration of the soil profile in the matrix of the disturbed precursor soil. In the concept of soil memory [1], it is relevant to distinguish anthropedic memory [2], which includes, inter alia, a set of morphological and functional features that are indicators of the regenerative post-anthropogenic dynamics of soil bodies. Tonkonogov and Lebedeva [2] have identified the restoring and developing trends that differ in the degree of anthropogenic disturbance/destruction of the precursor soil. We [3] proposed three main variants of the soil renaturation dynamics: primary (on exposed rocks and anthropogenic materials), recent (quasi-primary, on redeposited soil material with a disordered soil matrix), and secondary reproduction on degraded (abraded) soil. Wherein, in the secondary reproduction, it has been proposed to distinguish between secondary demutational (restoration of soil properties without the formation of a regeneration profile – during self-purification, decompaction, restoration of pedobiocenosis)) and secondary applicative soil formation (with the formation of a regenerative profile built into the matrix of residual horizons of anthropogenically disturbed soil). In this case, the analogy with the applicative evolution of soils [4] is rather formal, since the soil-forming potential of the environment remains the same, but the ontogeny of the soil is superimposed. Wherein, over time, the signs of agrogenic transformation of the precursor soil are erased – a classic variant of the palimpsest recording of soil information [5]. Undoubtedly, the postagrogenic humus-accumulative horizon (small soil index – pa, [6]) can be considered as the most obvious morphological sign of secondary applicative reproduction of soils.

The first fundamental generalization of the experience of studying the postagrogenic soils in Russia is the monograph "Dynamics of agricultural lands in the XX century and postagrogenic restoration of vegetation and soils" [7]. In the last decade, the interest to the study of postagrogenic soil dynamics has increased significantly. Moreover, somewhat more numerous works, the geography of which is confined to the regions with strong "soil schools" – related to the boreal zone [8–10]. The studies should be noted separately, in which a transzonal approach was used to identify the regularities of the regeneration of postagrogenic soils [11, 12].

With regard to postagrogenic soils of the forest-steppe, it was noted [11, 12] that the degree of reproduction of their organic matter is less pronounced than in postagrogenic soils of the boreal zone, which is explained by a relatively high content of organic matter in the arable horizons of soils that have passed into the state of fallow. Initial genetic differences in degraded agricultural soils significantly affect the rate of reproduction [13]. At the same time, the rate of soil formation in regenerative ecosystems differs significantly under various combinations of substratum and vegetation conditions [14]. Probably, the intensity of the manifestation of soil regeneration characteristics in any natural zone will depend on the degree of degradation of the precursor soil. Thus, in the Chernozem soil-geographical area, the post-agrogenic regeneration signs will be more noticeable in the soils where moderately eroded and severely eroded agrosoils were the precursors. Wherein, different variants of postagrogenic soil reproduction can be present in the same contour of the agricultural landscape, where soils of different types and degrees of degradation occur.

In this study, we attempted to characterize various variants for soil reproduction in the agricultural landscapes of the Central Russian forest-steppe, using the example of middle-aged (about 30 years) fallows, studied in the eastern part of the Belgorod region (Krasnogvardeisky district).

2. Study area

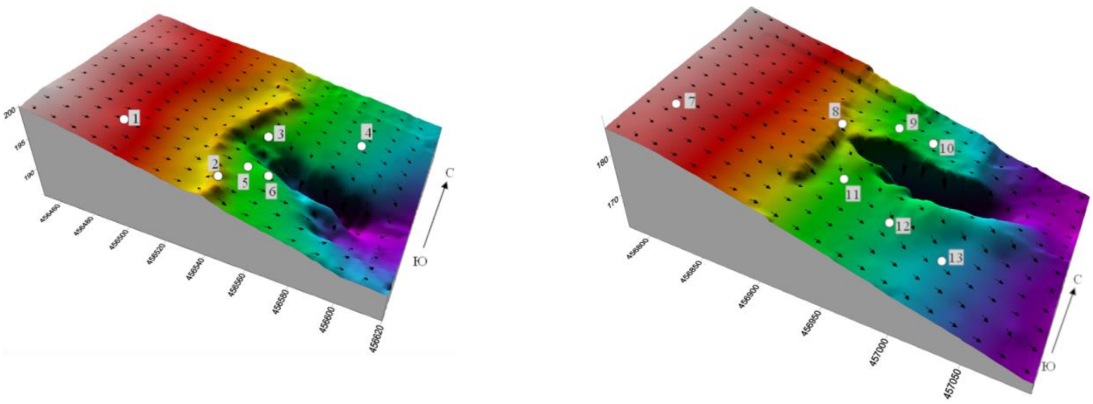
At the turn of the 21st century, during the crisis in Russian agriculture, the post-agrogenic restoration of arable soils after abandonment covered significant areas (over 40 million hectares) [6]. However, in addition to spontaneous renaturation, there are areas in agricultural landscapes for the purposeful withdrawal of lands from use when introducing landscape-farming systems. So, in order to stop the growth of ravines in the Krasnogvardeisky district of the Belgorod region, water retention embankments were widely used, which were arranged at the top of the ravines along the isohypsums [15]. The combination of stock-regulating forest belts and water retention embankments in most cases contributed to the stopping of the growth of ravines in this area. At present, the ravines are spontaneously overgrowing with trees and shrubs.

We carried out the study on the territory of the enterprise JSC "Samarinskoe" with the introduced landscape farming system near the village Nikitovka of Krasnogvardeisky district. Under the protection of forest belts and water retention embankments, natural soil reproduction occurs in conditions of a fallow aging over 30 years. The background agrosoils of the plots are clay-illuvial agro-Chernozems and agro-gray forest soils.

Plot No. 1 is a polygon with linear dimensions of 100 × 150 m, which includes a field with sunflowers, a fragment of a 3-row stock-regulating forest belt, a W-shaped water retention embankment, 1.5 m high, 108 m long, and the top of a ravine on the slope of the right-bank part of the valley of the river Polatovka. The plot is a south-eastern slope that is used as hayfield with little current grazing, but probably it was more significant in the past. The plant association is an herb-cereal plant with a protective cover of 80–90%.

Plot No. 2 is a polygon with linear dimensions of 100 × 200 m, which includes a field with a harvested crop of vetch-oat mixture, a V-shaped water retention embankment 1.2 m high, the top of a large ravine on the slope of the eastern exposure. There is no forest belt. The plant association is similar to that of the plot No. 1. The feature of Plot No. 2 is a combination of two land-use regimes: below the embankment on the south side of the top of the ravine, there is a cultivated field, and on the north side there is a perennial (more than 30 years old) fallow used as hayfield. This allows us to compare the results of natural soil reproduction and "cultural soil formation" in significantly different land use regimes.

A geodetic survey was carried out on the surveyed areas, which made it possible to obtain Digital Elevation Model (DEM) of the surveyed areas. The results of DEM processing showed that the erosion protection structures of the studied areas contribute to the interception of surface runoff from the adjacent agricultural lands (figure), which sharply reduces the intensity of erosion processes and favors to expanded soil reproduction.



Plot No 1 Plot No 2

Figure. Flow directions in key areas with anti-erosion plots. The punsons marked the position of the soil sections.

In the studied plots, 13 soil profiles were formed: plot No. 1, numbers 1–6; No 2, numbers 7–13. Wherein, sections 2–6, and 8–10, and agrosoils – by sections 1, 7, 11–13 (figure), represent regenerative soils. Sections 2 and 8 describe the soils that are formed from the soil material on anti-erosion dikes, which correspond to the variant of recent reproduction. Section 5 characterizes pedogenesis on displaced soil during the construction of the anti-erosion dike, which can be considered as an intermediate variant; let us call it recent-applicative reproduction, as well as section 6, this reproduction on scalped soil, in which the upper part of the profile was cut off by a bulldozer during the construction of the embankment. Sections 3, 4, 9, 10 are postagrogenic soils with applicative reproduction on abraded soil, with varying degrees of profile preservation. The objects presented in this material, of course, do not form "pure" genetic series, but they make it possible to identify some empirical regularities presented below.

3. Method of research

To determine the functional characteristics of soils, standard methods of analysis were used: the content of total organic matter by by Tyurin's method as modified by Simakov (by oxidation of the organic substance with a solution $K_2Cr_2O_7$ in sulphuric acid); pH(H_2O) by the potentiometric method, the fractional composition of humus by the Tyurin method as modified by Ponomareva and Plotnikova.

4. Results and discussion

Reproduction of soils in fallow areas occurs in accordance with the same ontogenetic regularities as in newly exposed parent rock, with the difference that "parent rock" in this case is agrogenically modified, usually degraded soils. Newly formed regenerated humus horizons are formed on the surfaces, which are represented by abrazems, luvisols and on the mounds formed by a mixture of soil and subsoil. They

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are clearly identifiable visually because significantly differ from the underlying horizons in color, structure, and composition because of functional and morphological reorganization of the profile.

Table 1 gives a brief description, the values of the thickness of the soil horizons, pH(H_2O) and the humus content in the studied soils.

Table 1. Characteristics of soils of one agrolandscape in the trends of renaturation and agrogenesis (Krasnogvardeisky district, Belgorod region).

Site No.	Characteristics of the soil reproduction option	Horizon	Depth/thickness, cm	Humus, %	pH_{H_2O}
1	Agrochernozem clay-illuvial medium eroded out, gleyed	PU	0–25/25	2.03	6.95
		AEL	25–31/6	–[a]	–
		BI	31–56/25	0.57	6.52
		BIg	Below 56	0.35	7.06
2	Remarkable soil formation on the embankment of the anti-erosion rampart	AU	0–10/10	2.10	5.87
		Chi[TUR]	10–23/13	2.11	6.29
		C[TUR]	Below 23	2.44	6.01
3	Applicative soil formation on highly eroded off gray forest soil	AUpa	0–10/10	6.33	6.37
		[AEL]	10–19/9	2.87	6.75
		[BT]	19–31/12	1.02	7.64
		[BCA]	Below 31	0.88	7.99
4	Applicative soil formation on highly eroded off gray forest soil	AUpa	0–11/11	4.58	6.47
		[AEL]	11–29/18	3.97	6.8
		[BT]	Below 29	1.12	6.48
5	Recent soil formation on displaced soil-soil overlapping clay-illuvial chernozem, medium eroded out	AU	0–12.5/12.5	3.27	6.32
		RU	12.5–28/15.5	2.38	6.65
		[PU]	28–45/17	3.79	6.78
		[AU]	45–60/15	1.24	7.97
		[BCA]	Below 60	0.67	8.22
6	Applicative soil formation on scalped clay-illuvial chernozem	AU	0–13/13	2.89	6.73
		[BI]	13–45/32	0.95	7.65
		[BCA]	Below 45	0.79	8.17
7	Agrochernozem clay-illuvial medium eroded out	PUrh	0–22/22	3.23	6.16
		AU	22–35/13	2.56	6.7
		BIh	35–52/17	1.40	7.11
		BI	Below 52	1.13	5.57
8	Remarkable soil formation on the embankment of the anti-erosion shaft	AU	0–10/10	4.27	6.74
		Chi[TUR]	10–24/14	2.00	6.72
		C[TUR]	Below 24	2.06	7.37
9	Applicative soil formation on clayey-illuvial chernozem strongly eroded away	AUpa	0–10/10	3.66	6.84
		[AU]	10–27/17	2.65	7.13
		BI	Below 27	0.76	6.23
10	Applicative soil formation on clayey-illuvial chernozem with highly eroded out	AUpa	0–12.5/12.5	5.63	6.79
		[AU]	12.5–28/15.5	1.90	6.74
		BI	Below 28	1.16	7.11
11	Agrochernozem clayey-illuvial strongly eroded out	PU	0–23/23	3.42	6.34
		AU	23–29/6	1.14	6.82
		BI	Below 29	1.13	7.01
12	Agrochernozem clay-illuvial strongly eroded away	PU	0–20/20	2.46	6.45
		BI	Below 20	0.68	6.88
13	Agrochernozem clay-illuvial strongly eroded away	PU	0–22/22	2.58	6.64
		BI	Below 22	0.91	6.68

[a] A dash in the table means “Not defined”.

Analysis of table 1 shows that in the regime of natural reproduction, humus horizons with a thickness of 10–14.5 cm were formed in soils. This corresponds to an average formation rate of about 4 mm yr^{-1} or 4 t ha yr^{-1}. While, in agrosoils, even under the protection of a water-retaining embankment, the process of degradation continued, which was accompanied by plowing of the underlying soil horizons and a decrease of the humus content in the arable layer.

The newly formed humus horizon in the studied regeneration soils differs for the variants of recent and applicative reproduction. On the mounds of anti-erosion dikes, its thickness and humus content are lower, the structure is less pronounced (significant participation of silty and coarse blocky separates), and the bulk density is lower compared to the postagrogenic humus horizons of the fallows. Of course, the relief of the embankments has a certain influence. It forms drier conditions of pedogenesis, with specific vegetation that supplies less residues to regenerative soils. The revealed regularities are confirmed by comparing the soil of section 5, which was formed on the humified soil-and-subsoil, moved by the bulldozer during the construction of the anti-erosion dike. Although the thickness of the postagrogenic horizon is comparable to the variants of applicative reproduction, the humus content is lower. An intermediate reproduction variant is also typical for the soil of section 6: it is formed on the surface, which was cut off by a bulldozer during the construction of an anti-erosion dike. Wherein, the humus horizon of the soil was completely destroyed, and only the illuvial part of the profile remained. Nevertheless, the thickness of the newly formed horizon near the soil of section 6 is higher than in the soil of section 5, because the matrix of residual horizons remained.

The presence of a residual profile of agrosoil destroyed by erosion significantly facilitates the reproduction of the postagrogenic humus horizon, but at the same time, part of the organic matter (and its composition) is inherited from the arable horizon. The degree of influence of the inherited humified material on the organic matter composition of regeneration soils can be revealed by comparing the fractional composition of their organic matter with the arable horizons of the background agrosoils.

Table 2 shows the results of determination of the fractional composition of organic matter for some of the studied soils. The organic matter of regeneration soils as a whole has a more fulvic composition; it contains more free humic acids and more humin, and a narrower C : N ratio than in arable soils. This indicates the accumulation of newly formed low-molecular-weight humus and low-humified organic matter in the recovering soils, and this is more noticeable in the situation with recent genesis (on low-humus soils and subsoils).

Table 2. Results of fractional analysis of humus (carbon (C) of humus fractions, % to C of total soil) and total nitrogen (N) content postagrogenic and agrogenic soils.

Site No.	Horizon	Thickness, cm	C, %	C_{HA}, %[a]			C_{FA}, %[b]				C_{HA}: C_{FA}	C : N
				HA–1	HA–2	HA–3	FA–1a	FA–1	FA–2	FA–3		
5	AU	0–12.5	1.84	4.18	20.28	4.51	5.92	0.33	10.76	9.18	1.11	10
6	AU	0–13	3.09	2.56	14.85	9.09	5.63	2.30	8.74	12.91	0.90	11
8	AU	0–10	2.76	3.59	17.82	7.64	5.54	2.29	13.91	14.02	0.81	10
9	AUpa	0–10	2.27	1.32	25.90	3.44	6.08	0.13	11.37	14.89	0.94	12
10	AUpa	0–12.5	2.48	1.45	29.84	6.81	5.44	0.29	10.03	8.47	1.57	11
11	Ap	0–23	1.92	2.19	26.77	4.90	3.85	1.15	10.10	9.37	1.38	12
12	Ap	0–20	1.32	1.67	30.00	5.30	5.76	0.68	9.32	9.17	1.45	10

[a] HA–1 is free fraction and associated with mobile sesquioxides; HA–2 is a calcium bound fraction; HA–3 is the fraction associated with the clay fraction and stable sesquioxides.
[b] FA–1 is aggressive fraction; FA–1a is fraction associated with HA–1; FA–2 is HA–2 fraction; FA–3 is a fraction associated with HA–3.

The soils of the recent variant of reproduction are also characterized by an increased content of the fraction of humic acids, which are associated with sesquioxides. The applicative variants are somewhat closer in the composition of organic matter to arable soils, but they also have signs of its accumulation and renewal. Thus, regenerative changes during applicative (postagrogenic) soil reproduction are associated largely with morphological organization and quantitative increase in functional characteristics. While for recent reproduction, the ontogenetic dynamics of properties is typical, when functional signs are formed anew. Old-age fallow lands already have a set of indicators for diagnosing pedogenesis processes with characteristic times that exceed the duration of the initial phases of vegetation and soil succession [16].

5. Conclusion

Using the example of the studied areas of middle-aged deposits in the Krasnogvardeisky District of the Belgorod Region, it is possible to determine the main variants for natural soil reproduction in agricultural landscapes:

1) applicative reproduction on agrosoils with a preserved humus horizon of different thickness as the most common variant;

2) recent reproduction on soil-and-subsoils, which are turbated mixtures of soil horizons;

3) intermediate variants- in the case of abrasion of the soil profile to the median horizons or in case of thin deposition of soil material (washed-out soils or technogenically disturbed fill-up soils).

Abrasion (removal of the upper part of the soil profile) is a disturbing effect on the soil, which leads to change in the functional relationship of the soil horizons. Because of regeneration, an applicative soil profile is formed, which is superimposed on the matrix of the residual horizons of the abraded soil. The signs of a regenerating humus-accumulative horizon substitute the signs of the exposed horizon, and the underlying layers are modified in accordance with the formation of a new system of links in the soil system. Wherein, applicative regeneration affects that part of the soil profile that corresponds to the ontogenetic level of functioning of the soil system. The direction of the regeneration process in this case will correspond to the zonal (modern bioclimatic) trend of pedogenesis. The rate of applicative regeneration will exceed the rate of formation of newly formed primary and recent soils, since the applicative soil, profile develops in the system of existing channels and inherits the degree of transformation of the parent rock by the precursor soil.

The results obtained confirm the possibility of using the potential of natural soil reproduction for their environmental rehabilitation. Regenerated soils support the sustainability of ecosystems that can be used as pastures and hayfields with some economic benefit.

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