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PEDOLOGY

Restoration of Agricultural Lands Affected by Erosional Degradation

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Abstract—The characteristics of bioclimatic dependence of restoration of the humus horizon of soils with different degrees of its preservation are established. The prospects of using an adaptation model of ecological restoration of lands degraded as a result of erosion are shown.

Keywords: soil erosion, degraded lands, soil restoration, agrolandscape
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Concerning degraded lands in Russia, Regulations for Conservation (1992) and Recommendations on Identifying Them (1994–1995) have been worked out, which creates conditions for temporarily withdrawing such lands from agricultural circulation. The introduction of a conservation regime is substantiated by the fact that strongly degraded and destroyed agricultural lands with their subsequent use for the intended purpose promote the development of negative processes and worsening of the state of soils and ecological situation.

In the Central Chernozem Zone, in addition to the problem of recultivation of postindustrial waste dumps (iron ore complex of the Kursk Magnetic Anomaly [KMA], production of building materials), no less important is stopping degradation of severely eroded and washed-out lands with the subsequent prospects of restoring them. The total area of severely eroded arable soils has already reached 128,000 ha and moderately eroded, 577,000 ha; it is considerably more outside of arable land. In the Belgorod oblast, it was established from remote-sensing results [1] that, during 30 years, the area of severely eroded soils increased by 18,000 ha and reached 170,000 ha, which with incompletely developed soils on carbonate rocks amounts to 11.8% of the total area of the oblast.

Ecological optimization of the balance of lands (according to type of use) is needed for stabilizing soil degradation processes, which from the standpoint of a systems approach can be achieved by introducing landscape-ecological agriculture projects on the basis of contour-ameliorative organization of the territory. Such development of agrolandscapes presumes the systematic and synchronous ordering of the entire rural locale, including lands of ameliorative resources (these are the greater part of pasture and gully and ravine lands).

Optimizing the structure of land resources inevitably requires transformation of lands with withdrawing the most destroyed lands under natural biotopes from agricultural circulation. With grassing and forest amelioration of such lands as well as with constant use of soil-improving crop rotations on moderately eroded soils, conditions for restoring soil fertility close to natural soil formation in effectiveness are created. However, in this case the outlook for restoring the natural and economic significance of lands of degraded territories in an economically acceptable time is not clear.

The result of field investigations conducted by the authors at the Belgorod State National Research University since 1995 allowed forming a statistically substantiated soil-chronological database of 400 objects: soils of different ages that formed under different substrate and phytocenotic conditions. It is intended for investigating the space–time regularities of restoration of soil resources, modeling processes of soil ontogenesis as well as a system of regional standards for monitoring soil regeneration processes. On the basis of this database [2], mathematical models were developed which adequately describe nonlinear (exponential, sigmoid) trends of development of processes forming the resource characteristics of zonal soils. The models allow, in particular, determining the threshold of resistance of soil to loss of the main resource evaluation properties (thickness of the humus horizon and humus content in it).

The use of mathematical methods makes possible an adequate description of the multifactor processes of restoration of soil resources. Modeling of processes of formation of the humus horizon and humus accumulation in soils is characterized by the highest degree of study [3]. For evaluating and predicting anthropogenic effects, the models should be able to take into account the main external factors determining the change in direction of the pedogenic process. This

Table 1. Average annual rates of formation of humus horizon (ΔH) and humus accumulation (ΔHA) for some zonal objects in a natural soil restoration regime

Region, investigated area	Zonal soils	Q, MJ/(yr m^2)	Object, age (years)	H, mm	ΔH, mm/yr	HA, %	ΔHA, %/yr	ΔHA, g/(m^2 yr)
Leningrad oblast, Slantsy	Sod-podzolic	958	Military trenches, 60	140	2.33	2.11	0.035	56.62
Orel oblast, Novosil Zonal Agroforestry Experiment Station	Gray forest	1015	Forest amelioration of eroded lands, 60	195	3.25	4.47	0.075	167.07
Belgorod oblast, Belgorod	Forest-steppe chernozems	1114	Military trenches, 57	194	3.40	4.55	0.080	178.09
Staryi Oskol (KMA)	Ditto	1082	Otvaly, Waste dumps, 44	54	1.23	2.34	0.053	33.03
Krasnodar Krai, Taman	Southern chernozems	954	Dugouts, 60	41	0.68	4.87	0.081	38.27
Republic of Crimea:								
Sevastopol	Brown mountain forest	953	Military trenches, 57	60	1.05	8.20	0.144	99.26
Simferopol	Calcareous chernozems	1195	Otvaly, Waste dumps, 50	60	1.20	6.60	0.132	91.08
Kerch	Southern chernozems	943	Military trenches, 61	90	1.48	4.12	0.068	69.90

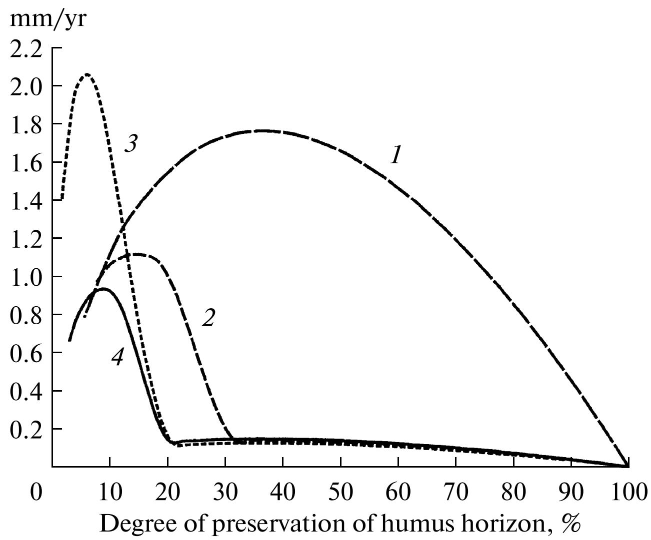
especially concerns parameters reflecting the bioclimatic influence of soil evolution factors.

Formation of the soil humus horizon depends on zonal climate conditions as well as on the characteristics of organic and mineral interactions under given conditions. In addition to the soil formation potential of natural factors, the intensity of regeneration soil formation is determined by the degree of degradation of the soil system and area of disturbances. The bioclimatic determination of soil geographic regularities clearly manifests itself in latitudinal zonation on plain territories (e.g., on the East European Plain) and in various soil zones of the shadow effect of mountains (Crimea, Caucasus). Table 1 gives some dynamic indices of restoration of the humus horizon and humus accumulation in various situations of disturbance of the soil cover for different natural zones. The investigated objects characterize automorphic restoration of soils on a loam substrate with the participation of vegetation of zonal habit. The given rates of soil formation processes are considerably (by one or two orders of magnitude) higher than their rate in mature soils. This attests to the capacity of zonal ecosystems for comparatively rapid restoration of the most ecologically significant soil component, the humus horizon, which allows the wide use of such characteristic during ecological rehabilitation of disturbed lands, including agricultural.

The earlier established relation[4] of the production process and energy consumed for soil formation, Q, makes it possible to determine the range of values of the average annual production of vegetation (on a dry matter weight basis), which corresponds to the Russian zonal soil types (Table 1), from 6 to 9 t/ha/yr. The differences in the rate of processes for the objects are due to different energy consumed on soil formation as well as the type and scale of disturbance of the soil cover. In the case of local disturbance (pits), the rate of soil regeneration processes is higher than in the case of large-scale disturbance (overburden dumps). The rate of restoration of erosion degraded (washed-out) soil is higher than during the formation of newly formed soils.

Thus, it is expedient to assess the potential of soil restoration in anthropogenically disturbed landscapes with consideration of zonal climate conditions (to a certain degree being transformed by the topography) as well as on the basis of a local diagnosis of the degree of degradation of the soil cover, substrate and phytocenotic conditions of the disturbed territory, and state and regeneration potential of the background ecosystems.

Restoration of soils is a continuous process of formation and/or progressive development of recent soil properties, including soil fertility resources, under the effect of soil formation factors [5]. Restoration of soils on newly exposed parent material is among the most important regeneration processes of natural geosystems or their restorable analogues. Unlike the formation of soils in the Holocene, there is no original “slow growth” phase during recent soil formation. It was established as a result of modeling the process of soil development in time that the rate of restoration of the humus horizon of soils is determined by the degree of their ontogenetic maturity (figure).The initial stages of pedogenesis are characterized by higher rates of soil restoration compared to the actual stage of development of full-profile soils. The most rapid restoration of



Dependence of the rate of soil formation (mm/yr) on residual thickness of the humus horizon of various soil types (subtypes): (*1*) sod-podzolic; (*2*) gray forest; (*3*) forest-steppe chernozems; (*4*) southern chernozems.

soils occurs during formation (restoration) of an ecologically "sufficient" thickness of the humus horizon due to the possibility of soil to steadily perform ecosystem functions. Calculations with the use of models (calculation of critical points – the maxima of the rate minima of the acceleration of growth) show that this thickness for chernozems is 20% of the limiting, for gray forest soils 30%, and for sod-podzolic 80–90%. Therefore, for soils of the forest steppe and steppe, ecologically critical is a loss of 70–80% of the humus horizon thickness, whereas for sod-podzolic soils, 10–20%. At the same time, soils of the forest zone can display regeneration possibilities already with insignificant disturbance of habit, whereas soils of the forest steppe and steppe are able to use for a long time the ecological reserve of stability at a rate ΔH not higher than 0.2 mm/yr.

The rates ΔH given in the figure for various soils types are inherent to zonal types of ecosystems and characterize average soil formation conditions. But a substantial range of the pedogenic capacity of natural factors is possible within the same natural zone. Investigations of young ecosystems in the forest steppe showed that the pedogenic potentials of combinations of substrate and phytocenotic conditions realized in the structure and properties of newly formed soils vary widely [6]. In the practice of renaturation of technogenic landscapes, this characteristic determines the need to select optimal combinations of types of substrate and vegetation for effective regeneration of soils. Increased sensority of soils at early stages allows managing soil formation and correcting its direction by selecting complementary combinations of substrate and biotic factors. The most intensive restoration ΔH is possible upon creating and/or stimulating the natural formation of herbaceous communities providing the maximum level of entry of organic matter into soil. For areas of agrogenically destroyed soils, long (more than 30 years) grassing with subsequent grassland agriculture with minimum tillage can be recommended.

The main goal of the biological stage of recultivation of lands disturbed by the mining industry is usually formulated as "planting trees and shrubs on disturbed lands" [7]. In our opinion, guidelines have presently been established for ecological restoration of anthropogenically altered landscapes, including both the formation of a topography with prescribed properties (geodynamic and antierosion stability, sufficient degree of diversity for ecological niches, etc.) and design of a stable landscape-adapted soil and vegetation cover. Abroad, the guidelines for ecological restoration are being developed with the organizational support of the Society for Ecological Restoration International [8].

To increase the effectiveness of fertility conservation and restoration programs, it is expedient to coordinate the effectiveness of planned ameliorative actions (species composition of forest plantings, composition of grass mixtures, application of fertilizers and amendments) with the standards of the limiting rate of formation of the humus horizon and optimal humus accumulation. When determining the direction, system, and technology of phytomelioration, it is necessary to take into account the mechanisms of interaction of life forms, species, ecotypes, and varieties of fodder plants with their combined growing so that, when designing models of perennial lands, the cooperative effects arising are used most effectively (on the basis of the principle of mutual complementarity of species in communities) [9]. Furthermore, having desynchronized the rhythms of vital activity of species, it is possible to reduce competition for factors of life. The restoration ecosystem can consist of new combinations of local species which are collected to correspond complementarily to the new conditions of the edaphotope [8].

Ecological restoration of lands adjacent to agrolandscapes increases biological and landscape diversity and has ecological regulative, resource restoration, and economic importance. During a change in the flora composition and productivity of communities, the phase from the time of sowing the grass mixture to its degeneration, which requires repeated tilling of the soil, and the phase of regeneration of the grass mixture into a natural cenose or one similar to it are monitored.

It was shown in experiments on ecological restoration [10] that surface tillage to a depth of 3–5 cm is less effective than shallow to a depth of 10–15 cm: an increase in the number of species (by 28%) and higher productivity (by 11%) were noted by the third year of renaturation of a steppe community with shallow till-

Table 2. Rate of restoration (mm/yr) of incompletely developed (degraded) soils with surface and shallow tillage to the depth of the humus horizon

Soils	Surface tillage to 6–8 cm	Shallow tillage to 8–12 cm
Sod-podzolic	1.71–1.76	1.76–1.52
Gray forest-steppe	1.10–1.12	1.12–0.94
Forest-steppe chernozems	2.02–2.05	2.05–1.73
Southern chernozems	0.92–0.93	0.93–0.78

age. But from the viewpoint of restoration of the humus horizon of soil, surface tillage to a depth of 6–8 cm can to a greater extent stimulates securing the results of humification than shallow (to 12 cm) tillage (Table 2).

Thus, ecosystems of various zonal types are capable of limited (within the limits of the necessary level of stability) restoration of soils, which allows using this ability for ecological restoration of degraded lands. When evaluating the effectiveness of ecological land restoration programs, it is necessary to take into account zonal differences of bioclimate conditions and to make a local diagnosis of the degree of disturbance of the soil cover and regeneration potential of soil formation because under conditions of natural restoration of the soil and vegetation cover the average annual rates of formation of the humus horizon can differ fivefold and rates of humus accumulation up to fourfold.

The regeneration possibilities of soils are activated under the effect of mechanical disturbance of the soil profile, which is due to abrasion (including erosional) of its upper part. Maximum intensity of restoration of the soil humus horizon occurs under conditions when the degree of its preservation is below the ecologically sufficient level, which differs for soil types. The susceptibility of soil to a disturbing action and its ability to compensate losses of the humus horizon not exceeding the level of its ecologically sufficient thickness decrease in the series sod-podzolic–gray forest–forest-steppe chernozems–southern chernozems.

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