PERIODIZATION OF ANTHROPOGENICALLY DETERMINED EVOLUTION OF STEPPE ECOSYSTEMS

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UDC 581.524.34-56.074.6

This article analyzes the evolution of plant cover of the Northern Black Sea region resulting from the anthropogenic factor. It gives the dynamics of processes of humus formation, biogeochemical transformations, and soil erosion. The main evolutionary phases are distinguished, lasting 2600, 7550, 90-110, and 40 years, which reflect the polyclimax nature of steppe ecosystems.

At present, on the basis of comprehensive analysis of soil profiles of the Holocene, the descriptive stage of retrospective study of plant cover in the Northern Black Sea region has been completed, and the prerequisites have been created for quantitative prognostic evaluations of the functioning of evolutionary phases of steppe ecosystems. The space and time interrelations of natural processes make it possible, instead of measurements in time, to use evaluations of the level of productivity and the rate of biogeochemical flows in a synthesized space-time series representing successive stages of change in an ecosystem under the directional action of the factor being studied (Glazovskaya et al., 1972).

Investigations (1981-1989) were conducted in the Dnepr-Dnestr geobotanical district of the subzone of fescue—needle-grass steppes, with predominance of southern chernozems in the soil cover. Considering the possibility of reflection of steady change in the plant cover during formation of new stages of soil evolution (according to the characteristic time of the processes being analyzed), we distinguished historical-ecological periods and a corresponding series of phytocenoses. The procedure for studying the rate of input and transformation of organic matter has been set forth previously (Lisetskii, 1987a). A test on decomposition of green phytomass and dead shoots (from August 27, 1987) was conducted in 3-4-fold replication, using bags of synthetic screen (mesh diameter 1.3-1.4 mm) lined with nylon (diameter 0.25 mm). Determination of the contents of nitrogen and ash elements in plants, and also soil analyses, were performed according to generally accepted procedures. The field test was set up on plots 20 × 20 × 20 cm in size, to which soil was transferred from under fescue, wormwood-fescue, and wormwood associations, and fescue was sown on August 27, 1987.

The degree of plowing and structure of crop rotations as of 1981 for the territory of the former Kherson province was evaluated by superimposing its boundaries on maps of contemporary political and administrative division of five oblasts of Ukraine and Moldavia showing administrative districts.

The closest to the zonal vegetation of the Black Sea region in the Early Holocene (10,300-7700 years ago) is the *Stipeta capillatae* formation. In describing the vegetation of Kherson province, I. K. Pachoskii (1913) noted that "without a doubt, tyrsa, as we call this species, formerly covered the whole province with an almost solid blanket" (p. 26). Feathery needle grasses (*S. lessingiana, S. pennata*) reach the peak of phytomass significantly sooner (end of April-June) than *S. capillata*, but at that time it amounts to only 52% of the phytomass of feather grass in August. On account of aboveground parts and roots, steppe ecosystems annually received 12 tons/ha of plant matter, which determined an input of 2.4-2.5 tons/ha of humus (Table 1). On the basis of recording the rate of decomposition of individual structural parts and their contents of the most important organogenic elements (Ca, K, P) (Table 2), we calculate that 58.1 and 131 kg/ha of these ash elements enter the soil (0-20 cm layer) with litter-fall and dead roots of feather grass (*S. capillata*), while *Festuca valesiaca* (fescue) provides for input of 37.7 and 65.9 kg/ha, respectively. As a result, the soil under needle grass receives 1.8 times more organogenic elements than under

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I. I. Mechnikov Odessa State University. Translated from Ékologiya, No. 5, pp. 17-25, September-October, 1992. Original article submitted May 3, 1990.

0096-7807/92/2305-0281$12.50

TABLE 1. Input of Plant Matter and Evaluation of the Rate of Humus Formation (tons/ha) for Zonal Phytocenoses of the Black Sea Region (Generalized Results of Investigations in 1981-1988, n = 504)

Type of phytocenosis and its anthropogenic degree of change	Maximum phytomass of green parts	Dead biomass in aboveground layer	Annual litter-fall	Maximum phytomass of underground organs (0-20 cm)	Annual root-fall (0-20 cm)	Annual input of humus on account of		
						Litter-fall	Roots	Total
Fescue—needle-grass association (virgin land)	4,67	8,74	5,1	23,36	7,00	0,5—0,6	1,8—1,9	2,4—2,5
Needle-grass—fescue association (virgin land)	2,70	2,77	2,1	14,88	3,92	0,2—0,25	1,2—1,6 *	1,4—1,9 *
Forbs—needle-grass—fescue association (pasture)	1,33	1,45	0,7	13,33	5,31	0,07—0,08	1,7	1,8

*For soils with different particle-size composition.

TABLE 2. Chemical Composition and Rate of Decomposition of Structural Parts of Edificators of Evolutionary Successions

Plant species and its structural part	Contents, % of air-dry sample						Rate of decomposition in one year (August 27, 1987-August 27, 1988), %
	Ash	N	P	K	Ca	S	
Feather grass (*S. capillata*):							
Green phytomass	7,69	0,90	0,14	0,70	0,41	0,19	44
Dead shoots	5,31	0,82	0,13	0,23	0,67	0,17	35
Active roots	18,44	0,60	0,11	0,48	1,28	0,25	42
Fescue (*F. valesiaca*):							
Green phytomass	8,93	1,51	0,25	1,76	0,43	0,21	51
Dead shoots	9,83	0,89	0,15	0,37	0,64	0,19	24
Active roots	10,28	0,90	0,14	0,23	1,31	0,14	60
Austrian wormwood:							
Green phytomass	7,19	1,68	0,30	2,05	1,18	0,20	67
Dead shoots	12,64	1,00	0,17	1,20	1,08	—	44
Active roots	4,92	0,84	0,18	1,20	0,63	—	54
Crimean wormwood:							
Green phytomass	0,23	2,13	0,21	1,58	1,02	0,29	42

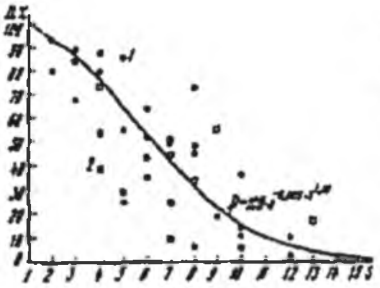

Fig. 1

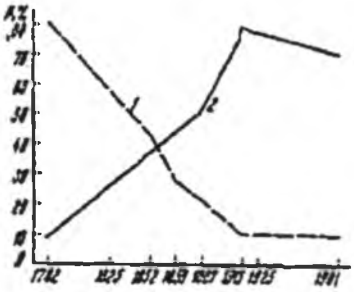

Fig. 2

Fig. 1. Dependence of concentration of Austrian (1) and Crimean (2) wormwood in aboveground phytomass (D, %) on number of species (S) on areas 25 × 25 cm in size: 1) Nikolaev and Odessa Oblasts, 1986; 2) Crimea Oblast, 1987.

Fig. 2. Dynamics of ratio of areas (P, %) under natural phytocenoses (1) and field agrocenoses (2) within the boundaries of Kherson district.

TABLE 3. Conditions and Results of Field Test

Indices	Association		
	Fescue	Wormwood-fescue	Wormwood
Phytomass, g/m^2	38.56	50.56 (including wormwood - 16)	60.00
Humus, %	3.21	2.78	3.64
Total nitrogen, %	0.204	0.198	0.224
Water extract:			
Dry residue, %	0.034	0.060	0,066
Cl^-	0,005	0.007	0,009
$Na^+ + K^+$	0,002	0.003	0.006
Mobile forms, mg/100 g:			
NO_3	6.44	6.16	4.76
P_2O_5	5.70	5.30	8.50
K_2O	30.00	30.00	89.00
Fescue phytomass, g/0.04 m^2:			
May 27, 1989	0.71	1.42	1.31
October 29, 1989	0.21	0.89	0.68

fescue, i.e., the value of needle grass is higher from the point of view of humus formation. This is also confirmed by other researchers (Bystritskaya et al., 1978), who established that, under needle grass, the 0-30 cm layer contains 1.7 times more humus than under fescue.

From the Middle Holocene, the pasture load and fires of anthropogenic origin become significant factors in the evolution of ecosystems. As a result of grazing, feathery needle grasses disappear first, then feather grass (*S. capillata*), and the more anthropotolerant disgressive fescue formation remains. This is due to the fact that, when phytomass is removed, 50% of needle-grass sod dies, and only 5% of fescue (Tanfil'ev, 1939). Pasture digression, which was even more intense in the Late Holocene, determined the formation of soils that had 25-28% less humus reserves in the 0-20 cm layer in comparison with the initial amounts (see Table 1). The portion of roots in the phytomass gradually increases from 83-84%, reaching 91% on pasture.

In the Black Sea steppes, wormwood participates slightly in the phytomass (Fig. 1) only in digressive successions characterized by the presence of 12 or more species in an area of 25 × 25 cm (the ratio of the number of species in areas 1 × 1 m and 25 × 25 cm is 2.00-2.67 in individual color aspects). With the transition of pasture to overgrazing, *Artemisia austriaca* forms wormwood steppe, which can degrade only as a result of sheep grazing. Overgrazed areas (fallow-field grazing, pastures) adjacent to populated points created a qualitatively new stage of the action of vegetation on soil formation, completing the series of digressive successions. As wormwood was concentrated, the role of its litter-fall in the biogeochemical flows of steppe ecosystems rose. This is connected with differences in the chemism and rate of transformation of phytomass of edificators of evolutionary successions. The sum of organogenic elements (Ca + K + P) in the green phytomass and roots of Austrian wormwood (see Table 2) differs little, amounting to 41-49% of total ash content, which is 2 and 3.4 times more than for fescue and feather grass, respectively. Crimean wormwood has similar chemism. The portion of undecomposed plant matter, which is easily determined according to the data in Table 2, characterizes the rate of flows: phytomass — dead shoots, dead shoots — litter, active roots — inactive roots, i.e., it gives an idea of peculiarities of the formation of dead biomass of the edificators of evolutionary successions.

A significant difference is noted in the rate of decomposition of litter-fall of wormwood and the grasses of primary groupings that it displaces. In one year (September 30, 1984-September 28, 1985), the weight loss of fresh dead shoots of fescue was 39.5%; and of Austrian wormwood, 55.8%, i.e., 1.4 times greater; and according to the data in Table 2, 1.8 times greater. On account of these factors, litter-fall of wormwood generates favorable conditions for growth of the given species, which is indicated by chemical indices of the soil and the productivity of artificially sown fescue (Table 3). Elements of potential (humus, total nitrogen) and effective (mobile forms of phosphorus and potassium) soil fertility have higher values under wormwood than under fescue. Besides that, the aboveground phytomass of wormwood is more enriched with nitrogen. However, in natural conditions, replacement of the places where wormwood grows by fescue and other grasses is not very likely. Austrian wormwood, possessing high alleopathic potential, depresses the growth and development of species that get into its synusia and also determines a sharp increase in the level of colins at the association's boundary (Grodzinskii, 1965). In such conditions, a smaller amount of exchange calcium in the soil's absorbing complex, a larger amount of salts, especially chlorine and sodium, and a significant excess of the limiting sulfur content noted in unsalinized habitats indicate formation of a halophytic situation in the soil medium. An intensifying pasture load leads to an increase in density of the soil structure, activation of evaporation, and greater regulation of the geochemical cycle in biomass and the upper soil layer.

Thus, the significant action of the preagricultural period of utilization of steppe ecosystems was determined not so much by the depth of anthropogenic transformations as by their constant manifestation over a long time: 7550 years. Agriculture developed in spots, and its effect was territorially mobile. Perhaps, the Ol'vin period (Sixth Century B.C. to the middle of the Third Century A.D.) was an exception, when the zone of agricultural development (plowed fields, vineyards, permanent pastures) in the interfluve of the Bug and Berezan estuaries, according to our estimates, was 44,000-55,000 ha, or 25-30% of the present area of agricultural land.

From the end of the Eighteenth Century, as agriculture developed in the Black Sea region, natural groupings of vegetation disappeared rapidly. Overall patterns of the dynamics of this process are revealed well on the example of Kherson district (Fig. 2). By the middle of the Nineteenth Century, temporary parity was established in the areas of plowed lands and natural phytocenoses, and by 1915 the practical limit of plowing had been reached, and localization of natural vegetation on the 10% of land most unsuitable for plowing was completed. During this historical-ecological period, a radical rearrangement of steppe ecosystems occurred.

Extensive development of agriculture in the Nineteenth Century is a distinctive stage in the use of soil resources, the main features of which are as follows: low yield, with sensitive variations depending on agricultural weather conditions; dominance of grain crops (four crops occupied 88% of the sowing area) and the absence of crop rotation; infrequent use of manure; and gradual stabilization of humus losses. The continuous dynamic series of spring-wheat yields, compiled on the basis of records of 21 farms of German colonists (in the present Tokmak and Chernigov districts of Zaporozh'e Oblast) during the period 1874-1889 (Postnikov, 1891) can be approximated by the equation $Y = 5 + 0.04X$, where Y is the yield; 0.04 is its annual increment, centners/ha; and X is the number of the year. The average yield during these years (5.3 centners/ha) differs little (5.6 centners/ha) from a more general 50-year period (1840-1889). Droughts, the main natural factor limiting harvests, occurred in the southeastern Black Sea region with probability of 40%. In these conditions, realization of climatic cycles, which established a clearly revealed rhythm of the production process, probably took place in a slightly altered form. The amplitude of variations in average extreme yields of five grain crops was 42-61%. For comparison, in a fescue—needle-grass association, over six years the amplitude of variations in phytomass was 41%; and in a needle-grass—fescue association (over five years), 59%.

Annual cultivation of the soil, providing for conversion of potential fertility to effective fertility on account of mineralization of humus, was done to a shallow depth (down to 12 cm); therefore, for the most part, a third of the contemporary thickness of the arable horizon was subjected to active agrophysical degradation and dehumification. In comparison with hay fields and pastures converted to plowed land, the loss of effective fertility of old plowed soils (not to be confused with humus losses) was already 25% during this period.

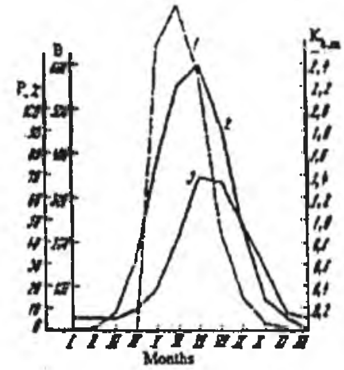

Fig. 3. Correspondence of annual dynamics of hydrometeorological condiitons of storm erosion of soil to soil-protection efficiency of natural vegetation in Kherson province and crop rotations in the Black Sea region: 1) hydrometeorological parameter ($K_{hm}\cdot10^{-3}$, tons/ha); 2) number of blooming species of natural phytocenoses (B); 3) projective coverage of crop rotations (P).

The change in plant cover connected with plowing of a large part of the territory determined the predominant degradation process: soil erosion. Comparison of the flowering curve for 1255 species of wild plants in Kherson district (according to results of É. Lindemann's research, 1872) with the annual distribution of amounts of the hydrometeorological parameter of storm erosion K_{hm} (the product of turbidity by the amount of erosion-forming precipitation) (Igoshin, 1980), generalized for 10 weather stations within the corresponding territory, indicates the high soil-protection efficiency of natural phytocenoses (Fig. 3). In the seasonal succession of aspects, a clear maximum is revealed in the number of flowering species (June-July). In this case, the majority of species are supposed to reach their maximum mass and amount of projective coverage during the flowering phase. The zonal plant cover, forming projective coverage of the soil surface of 60-90%, was an effective regulator of soil erosion losses, since, for the range of projective coverage from 50 to 75%, a balance of the rates of erosion and soil formation is noted (Lang and McCaffrey, 1984).

The soil-protection efficiency of agricultural crops in different vegetation periods and in the postharvest period was evaluated according to the dynamics of projective coverage. According to data from agroclimatic reference books for 1959-1987, we established the average long-term dates of the beginning of individual phases of crop development according to nine weather stations (Voznesensk, Pervomaisk, Bobrinets, Kirovograd, Zatish'e, Odessa, Ochakov, Kherson, and Novaya Kakhovka). A generalized curve of projective coverage (see Fig. 3) was derived on the basis of its dynamics for winter and spring grain crops, row crops, and annual and perennial grasses by phases of their development ("Critical..., 1984; Roshkovan, 1988) and their portion in the structure of the crop rotation. A disparity was revealed between the peak of storm danger, which comes in June, and the maximum projective coverage of crop rotations in July-August.

The presence of litter, as a buffer mulching layer, and an upper soil horizon well reinforced with roots determines the transformation of initial conditions of runoff formation and establishes the period of delay in realization of the water-erosion process. Litter at "Askaniya Nova" forms a layer 3-4 cm thick, and usually (due to fires) as much as 1 cm, and it possesses high moisture capacity (maximum water capacity) of 355% for an absolutely dry sample. Taking this into account, and also data on the averge long-term moisture content in May-September, the total moisture capacity of southern chernozems, and the probability of rains with different layers of precipitation for five weather stations in the Black Sea region with a total observation period of 139 years, we came to the following conclusion: during the period of storm danger, surface erosion of soil under the zonal steppe vegetation can happen only once in eight years. We will evaluate the average long-term rate of this process.

In the territory of the Black Sea region, in the overall amount of soil losses due to water erosion and deflation, storm erosion accounts for 69%. Being the dominant factor in the preagricultural period and at present, storm erosion, in connection with the sharply differing condition of the underlying surface, had a different action on trasnformation of the soil cover. We evaluated surface soil erosion during the summer-fall period according to G. I. Shvebs' model (1981):

TABLE 4. Generalized Initial Data and Calculated Amount of Storm Erosion of Soil

Groups of regions	h	S, %	Geomorphological conditions		Soil conditions	Climatic conditions	Structure of field crop rotations, %:					W, tons/ha		F, tons/ha
			L, m	I, deg	j_{R_0}	K_{hm}, tons/ha	1	2	3	4	5	In current conditions	In the preagricultural period	
I (forest-steppe and ordinary chernozems)	41	71	682	1,8	1,41	8,7	7	45	35	5	8	7,85	0,43	0,51
II (southern chernozems and dark-chestnut soils)	16	29	1055	1,4	1,76	8,3	6	48	32	7	7	8,41	0,52	0,43
Territory of the Black Sea region	57	100	790	1,7	1,51	8,4	6	48	34	6	8	8,00	0,45	0,49

Remark. h) Number of administrative regions; S) relative distribution of areas of arable lands; L) average length of slopes; I) average gradient; j_{R_0}) index of relative erodibility of soil; K_{hm}) hydrometeorological parameter; 1,2,3,4,5) fallow, grain crops, row crops, annual grasses, and perennial grasses, respectively; W) average annual modulus of storm erosion of soil; F) average annual rate of natural soil formation.

$$W_{s.o} = 1{,}5 \cdot 10^{-3} \cdot j_R \cdot I^n \cdot L^{0.5} \cdot \sum_{i=1}^{m} K_{hm} \cdot e^{-\lambda_V (0.85-100m)}$$

where $W_{s.o}$ is the average annual modulus of storm erosion of soil, tons/ha; j_R is the index of soils' relative erodibility; I is the slope gradient; n is an index that depends on the type of soil, degree of its erosion, and the agricultural background; L is the length of the slope; and $e^{-\lambda_V(0.85-100m)}$ is a function reflecting the effect of vegetation on soil erosion.

The rate of natural soil formation was evaluated according to the previously suggested model (Lisetskii, 1987b), taking into account the areas of soils with individual degrees of erosion. Results of the calculations (Table 4) show that, in the territory of the Black Sea region, in the preagricultural period the amount of storm erosion was comparable with the rate of natural soil formation and can be interpreted as the amount of geological erosion: 0.5 tons/ha per year. In 1989, judging from the degree of plowing and the established structure of crop rotations (portion of row crops — 3.2%), erosion losses of soil did not exceed 3.7 tons/ha per year. With the current structure of field crop rotations, row crops, in particular, reached 34% of the area of plowed land), the amount of accelerated erosion was 8 tons/ha; and thus, erosion destruction of lands of the Black Sea region has intensified by 17 times in comparison with the preagricultural period. At the same time, the quality of the soil resource has changed: during the whole period of agricultural use, southern chernozems have lost 19% of the arable horizon's humus reserves.

Over the last 40 years of development of dry-land argiculture in the region, a zonal, scientifically substantiated structure of crop rotations was determined; however, with relative consevativeness of the species composition and succession of plants in the agrocenosis, anthropogenic loads on soils rose (more productive varieties, agrotechnical factors of intensification, etc.). With the current level of yield in the Black Sea region, humus input on account of plant residues of crops is only 30% of the amount that characterized the rate of humus formation in the Early Holocene. The use of organic fertilizers has become an indispensable condition for maintaining the soil's potential fertility.

The evolution of plant cover in the Black Sea region under the directional action of the anthropogenic factor can be represented in the form of four successive time phases of different durations: zonal phytocenosis (2600 years) — digressive successions (7550 years) — agrocenosis of the extensive type (90-100 years) — agrocenosis of the intensive type (the last 40 years). In accordance with these phases, it is valid to distinguish a series of climax (quasiclimax) states of ecosystems, confirming the point of view about the polygenetic nature of the contemporary soil profile. Apparently, we can already talk about a new phase of development of steppe agroecosystems, which is now manifested on 13% of the arable land in the Black Sea region under the influence of irrigation.

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