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Functioning and Evolution of Biogeocenoses in the Baraba Lowland, West Siberia

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Abstract—This paper reports the results of quantitative analysis of biological cycle in individual ecosystems and multidirectional migration of chemical elements between adjacent ecosystems along a geochemical catena located in the Baraba lowland, West Siberia. The balance of carbon, nitrogen, salts, and the total of nonsalt components in soils of eluvial, transeluvial, and accumulative ecosystems, as well as the uptake of carbon, nitrogen, and ash-forming elements by the phytocenoses of these ecosystems, were estimated. The results were used for calculating so-called “abioticity” indices of carbon, nitrogen and the sum of salts and nonsalt components of biological cycle. Abioticity indices indicate the relationship between cyclic (biotic) and migration of elements (abiotic) processes. Carbon and nitrogen were found to be involved in the biological cycle of individual ecosystems. Most likely, these elements are not subjected to geochemical migration, whereas some amount of nonsalt components and a somewhat greater amount of salts are involved in migration according to the topographical features of the catena.

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Studies within the International Biological Program supervised by R. V. Kovalev and N. I. Bazilevich were carried out at the Karachi Biostation in the Baraba lowland from 1967 to 1972. The studies were aimed at consolidating the knowledge on biotic cycle and migration processes in soils into one system. Observations were made at a 2 km long geochemical catena, where eluvial, transeluvial, and accumulative positions represented by their typical biogeocenoses were segregated, totalling ten. In addition, we studied a meadow steppe ecosystem on typical chernozem at elevated crest of the relief, which was considered the first (upland) element of the catena, though the crest itself is beyond the catena. Actually, all the abiotic flows and the main metabolic processes of biotic cycles have been studied. The results were published as a two-volume monograph [1, 2] edited by R. V. Kovalev in 1974 and 1976.

The diversity of ecosystems and their interconnection at the water runoff defined the primary direction of the investigations, namely the quantitative estimation of biological cycles within separate ecosystems and flows or migration of matter between them. In order to achieve it, long-term monitoring observations were undertaken. A new method was employed to study the biotic cycling in grass-dominated ecosystems [3, 4].

To study the migration of water-soluble and colloid elements in geochemically interconnected landscapes, it was necessary to analyze the following:

(1) amount and chemical composition of precipitation, i.e., abiotic matter inflow into an ecosystem;

(2) migration of chemical elements through surface runoff, i.e., migration which interconnects ecosystems;

(3) vertical migration of chemical elements in the soil profile, i.e., the flow of substances from the upper to lower soil horizons, and possible outflow beyond the ecosystem;

(4) migration of chemical elements through the lateral interflow within the soil profile;

(5) migration of chemical elements through upward capillary flow, i.e., abiotic inflow of elements from underground water.

Thus, all abiotic vertical and horizontal inflows and outflows have been studied. The results obtained allowed us to estimate the balance of chemicals in soils of various ecosystems (elementary landscapes) taking into account precipitation, surface runoff, lateral interflow, upward capillary flows, and migration of chemicals into underground water. The balance estimations are shown in Table 1 for three ecosystems.

Based on data from Table 1, we conclude that migration of chemical elements is more active down the catena. Salt balance in the eluvial landscape is positive owing to inflow the elements with precipitation and low outflow. The transeluvial landscape loses substances while the accumulative landscape accumulates them.

Biotic cycling is much more active than abiotic one (Table 2).

Overall, we found high values of the net primary production (NPP) in grass-dominated ecosystems, varying from 16 up to 64 tons/ha (of dry matter) a year in alluvial and accumulative positions of the catene, respectively. As much as 60% to 70% of NPP is producing by underground organs of the vascular plants owing to the active transfer of assimilates from leaves down to roots. Diminished (or lower) concentrations of nitrogen

Table 1. Balance of chemicals in soils of various elementary landscapes, kg/ha a year

Inflow and outflow	Salts	Mineral substance excluding salts	C	N
1. Eluvial landscape; typical chernozem soil				
Inflow with precipitation	95	37	38	3.5
Outflow with surface runoff and lateral interflow	24	193	163	6.1
Balance	+71	–156	–125	–2.6
2. Transeluvial landscape; chernozem-meadow soil				
Inflow with precipitation, surface runoff, lateral interflow, and upward capillary flow	256	82	195	9.8
Outflow with surface runoff and lateral interflow	952	302	870	32.9
Balance	–696	–220	–675	–23.1
3. Accumulative landscape; peatbog soil in lakeside floodplain				
Inflow with precipitation, surface runoff, lateral interflow, and upward capillary flow	3423	504	419	24.3
Outflow into underground water	2788	54	51	1.7
Balance	+635	+450	+368	+22.6

Table 2. The amount of carbon consumed by the phytocenosis from the atmosphere and the amount of nitrogen and ash elements consumed by the phytocenosis from the soil of the catena ecosystem, kg/ha a year

Position and ecosystem	C	N	P	K	Ca + Mg	S + Cl + Na	Si + Fe + Al
Eluvial; meadow steppe hosted on typical chernozem soil	8260	330	33	121	400	72	760
Transeluvial; mesophyte meadow hosted on chernozem-meadow soil	12 300	385	21	213	708	120	1124
Accumulative; grass-dominated mire hosted on peatbog soil	32 000	650	171	274	657	305	2285

and potassium were found in hydrophilic vegetation at wetland sites. Owing to this, the wetland plants consume these elements two times more effectively than plants in steppe, while the productivity of plants in steppe ecosystems is four times higher than that of wetland ecosystems. Grasses accumulate considerable amounts of Ca^+ and Mg^+, 400 to 660 kg/ha a year. The cycles of chemical elements which are major components of soluble salines (S + Cl + Na) are different from the potassium cycle. Though K also forms water-soluble salts, unlike (S + Cl + Na) it is a biophillic element. The total contribution of (S + Cl + Na) to biotic cycle is lower than the consumption of K in eluvial and transeluvial ecosystems , although it is greater in accumulative ecosystem which consumes salt components at a rate of 3.4 tons/ha a year (see Table 1). The biotic outflow of nonsalt components (Si + Fe + Al) is greater than their inflow into ecosystems from precipitation, surface runoff, and upward-flowing solutions. The phytocenosis of the eluvial ecosystem consumes a twentyfold greater amount of nonsalt components, as compared with the matter inflow; furthermore, the consumption exceeds the matter input in transeluvial and accumulative ecosystems by a factor of 14- and 4.5, respectively. Therefore, Si, Fe, and Al actively participate in biotic cycles rather than are merely consumed from soil fluids by phytocenoses proportionally to their concentrations.

The abioticity index was introduced to describe the fluxes of elements in biotic and abiotic processes. The index is calculated as a ratio of the total abiotic inflow or outflow to the rate of uptake a certain element by phytocenosis [5]. Table 3 represents the abioticity indices for only total inflow. Since K, Ca, and Mg can

Table 3. Abioticity indices

Position and ecosystem	C	N	S*	*m***
Eluvial; meadow steppe hosted on typical chernozem soil	0.005	0.011	0.49	0.03
Transeluvial; mesophyte meadow hosted on chernozem-meadow soil	0.015	0.096	0.77	0.04
Accumulative; grass-dominated mire hosted on peatbog soil	0.013	0.036	5.91	0.16

* Salt components.
** Nonsalt components.

contribute to both salt and non-salt components, for convenience, we consider K a salt component, while Ca, Mg, and Pб non-salt ones.

Very low abioticity indices are found for C and N, whereas they are a little greater for nonsalt components, and much greater for salts in eluvial and transeluvial ecosystems. Abiotic cycle of salts in accumu- lative ecosystems is sixfold greater than biotic one. Therefore, biophillic elements, i.e., carbon and nitrogen, involved in transformation and migration processes are held by biotic cycling within the ecosystem. Insignificant amounts of nonsalts leave the biotic cycle and get involved into migration processes. The salt components actively participate in both cyclic and migration processes and are the major agents of matter exchange between ecosystems.

The topographical features of the landform along with the activity of biotic cycle and abiotic migration determine the ecosystem functions and the way of their evolution [6, 7]. General characteristics of the ecosystems at different positions along the catena including their evolution trends are given below.

Meadow steppes resting on typical chernozems are of the oldest relative age and close to the final phase of their evolution. The meadow steppes are forming in eluvial landscapes at the top of crests and/or upper thirds of high crest slopes. The water regime in this soils is non-leaching by percolation. The elements migrate via precipitation and surface runoff. Geochemical budget of nonsalt components is balanced, while it is slightly positive for salt components. The productivity of the above-ground phytomass (ANP) was estimated at 4 tons/ha a year, while the productivity of below-ground organs (BNP) appeared much higher — 15 tons/ha a year. Phytocenoses consume about 1013 kg/ha of mineral elements and 175 kg/ha of nitrogen a year. The biotic cycle is virtually closed, with periodic and stationary functioning regime [8]. The meadow steppes are undergoing further aridization and steppification, along with biological transformation of the residual solodization and salinization remained from the previous stages of soil evolution.

Forb meadows resting on chernozem-meadow solonetz-saline soils are forming in transeluvial landscapes. The water regime is periodically perlocative and exudational. The matter migrates predominantly via the surface runoff. The balance of water-transported substances is negative, while that of underground water-transported substances is slightly positive. Regarding the NPP its ANP component was estimated at 4.5 tons/ha, and BNP of 25 tons/ha a year. Overall, the phytocenosis annually consumes 1670 kg/ha of mineral elements and 343 kg/ha of nitrogen. The functioning regime is transitional with infrequent fluctuations. The ecosystem is evolving toward steppifying, the soils are transforming into meadow chernozems.

Grass-dominated marshes resting on considerably solodized peatbog soils are forming in accumulative landscapes. The water regime is perlocative and slightly exudational. The migration of chemical elements is determined by the surface runoff and downflow processes. The balance of water-transported substances is generally negative, while the salts balance is positive. The ANP is 10.7 tons/ha and the BNP is 21.2 tons/ha a year. The phytocenosis annually consumes 1720 kg/ha of mineral elements and 450 kg/ha of nitrogen. The functioning regime is transitional. Nowadays, the ecosystems are transforming into marsh-saline meadows with further salinization and lack of underground water.

We therefore conclude that the evolution of the ecosystems analyzed at the catena representing the landcover typical of southern part of the West Siberian Plain is directed to gradual drying, steppifying of the landscapes, and transformation of saline soils into chernozems.

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