The rate of soil formation in regenerative ecosystems with various combinations of substratum and vegetation conditions

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Annotation

The rate of soil regeneration in young ecosystems depends on the combination of substratum-vegetation conditions. Realization of soil formic potentials of biota and substratum can be appreciated by the speed of humus horizon formation. The maximal speeds of soil formation for basic combinations of substratum and biota types in forest-steppe are determined. The biolithocombinations with greatest soil formic potential must be recommended for renaturation of anthropogenic disturbed soils.

Key words: regenerative ecosystems, succession, soil regeneration rate, young soils, humus horizon, soil organic matter.

1. Introduction

The development of conception about restoration of anthropogenic perturbed soils on the basis of natural soil formation need the deep study of biota and substratum interaction in young ecosystems. The peculiarities of this interaction can be revealed during the investigations of recent soil formation results on once again exhibited substratum in typical for given natural zone ecotopes. The former investigation of natural filing up on the mine soil by vegetation [1-5] showed that the effectiveness of this process is mainly determined by the favorable qualities of substratum for settling plants on it. It was noticed that different types of phytocoenoses are not the same according to the degree of transforming influence on substratum. So it is necessary to distinguish such ecosystem characteristics as *soil formic potential of biota (SFPB)* and *soil formic potential of substratum (SFPS)* which are the components of *soil formic potential of environment* [6-8]. The effectiveness of realization of SFPB and SFPS is determined by the results of functioning of separate soil formation processes which include the interaction of mineral part of soil and organic matter (humus).

2. Material and Methods

We studied the peculiarities of interaction between substratum and biocoenose formed with it on the example of landscape ecosystems in Belgorod region, which were disturbed by World War II. The objects of investigations are unique, because we have exact determination of zero-moment in soil formation (1943 - the end of Kursk battle) and a large variety of type combinations of mother rock and phytocoenoses typical for forest - steppe zone. Young soils formed in automorphical conditions on the parapets of trenches and dugouts were studied in trenches of 4 m long. Morphological maturity of soil was appreciated by the thickness of humus horizon measured not less than 32 - multiple replications to form a large sample values. The rate of humus horizon formation is taken as a relative indicator of soil formation effectiveness. Besides there were determined some physical and chemical properties of new formed soils: mechanical composition, bulk density, color of dry soil, the humus content and total nitrogen, selectively - mineralogical composition (thermal analysis). The authenticity of difference of morphological soil maturity was established statistically by Kolmogorov - Smirnov criterion.

The effectiveness of biota regeneration was defined by studying the composition, the structure of phytocoenoses, the peculiarities of soil mesofauna in young ecosystems. The size of organic leaf fall substance and its deponing in litter were the indicators of biological cycling. The examined ecosystems were classified according to the types of vegetation and substratum. This made possible to examine the peculiarities of "biota - substratum" relation regarded from selected biolithocombinations.

3. Results and Discussion

Automorphycal young soils are the product of integral influence on exhibited substratum by such factors as solar radiation, atmosphere air, precipitation, and biota. And mother rock being recipient of these influence, it itself play active (sometimes basic) role in soil formic process. Among all soil formation factors the rocks and organisms leave material basis of pedogenesis in a great extend [8]. At early stages of soil development the interaction of these factors shows itself the most clearly. The fact was confirmed by investigation of structure and functioning of pedosystems 55 - 60 year ago in landscapes disturbed by World War II. Some properties and morphological peculiarities of young soils are given in the table 1. The profile of young soils has simplified structure: humus horizon of different thickness (from 17 to 218 mm); transition horizon (sometimes it is lacking especially on solid substrata); soil forming rock, which often has layer structure.

Table 1. – Thickness of humus horizon (H) and some characteristics of young soils on the different types of substrate

Type of phytocoenose*	H, mm	Color of dry soil**	Content of clay particles (<0.005 mm), %	Bulk density, g/cm^3	Humus	Nitrogen	C/N***
					In the layer 0-5 cm, %		
Loam							
Q	136	10 YR 4/2	15.80	1.08	5.22	0.219	13.79
A-Q	130	10 YR 4/2.5	17.03	0.99	4.14	0.217	11.06
T-Q	119	10 YR 4.5/2.5	21.28	1.06	3.72	0.251	8.57
A	109	10YR 5/3	20.52	1.20	3.52	0.209	9.46
Pop.	88	10 YR 5/3	10.26	1.13	2.07	0.142	8.45
Clay							
Herb.	91	10 YR 4.5/3	23.27	1.16	4.14	0.294	8.16
Q-T	88	10 YR 4/2	17.88	1.06	5.95	0.338	10.21
Q	77	10 YR 4/2.5	22.70	1.20	4.93	0.209	13.64
Sand							
Herb.	106	10 YR 3/2	7.09	1.15	4.83	0.325	8.62
Q-T	104	10 YR 4/2	11.35	1.24	3.57	0.209	9.90
Q	80	10 YR 3/1.5	2.95	1.13	2.78	0.350	4.60
Pop.	69	10 YR 4/2	7.31	1.20	2.46	0.172	8.31
Pin.	62	10 YR 3/2	3.00	1.11	2.48	0.361	3.99
Chalk							
Herb.	123	10 YR 4.5/1	4.26	0.61	10.57	0.254	24.09
T	114	10 YR 6.5/1	17.03	0.78	6.75	0.268	14.59
Q	109	10 YR 5/1.5	11.07	0.99	4.96	0.266	10.79
Pop.	91	10 YR 7/1	12.77	0.93	3.92	0.183	11.48
Marl							
Herb.	181	10 YR 6.5/1	14.19	0.96	5.48	0.335	9.46
A-T	144	10 YR 6/1.5	14.47	0.99	4.94	0.238	12.02
Q	106	10 YR 5/3	15.89	1.16	4.83	0.277	8.84
Pin.	59	10 YR 6.5/1.5	15.89	0.85	5.22	0.322	9.38

*Types of phytocoenose: Q – oak forest *(Quercus robur*); A – maple forest (*Acer platanoides*); T – linden forest (*Tilia cordata*); Pop. – asp forest (*Populus tremula*); Pin. – pine forest (*Pinus sylvestris*); A-Q – maple-oak forest; T-Q – linden-oak forest; Q-T – oak-linden forest; A-T – maple-linden forest; Herb. – herb vegetation.

** Munsell Standard soil Color Charts

*** Total carbon and total nitrogen ratio in the soil

All variety of mother rocks should be classified into 5 types distinguished by peculiarities of mechanical, mineralogical composition and by specific features of connecting of humus substances. The formation of humus horizon in the young soils is the result of self-organization by two abiotic processes: the interaction of humus and pro-humus substances with minerals on the surface of substratum particles (the creation organic-mineral forms) and penetrating of their solutions deep inside substratum under influence of gravitation forces [9, 10]. Evidently these processes are more balanced in substrata containing clay particles (less 0.005 mm in size) from 15 % to 20 % (loam). In this case it is provided the effective creation of humus horizon with rather high content of organic substance in it. Such properties are typical for loess-like loam, moraine loam, and marl rock. In the case of more light mechanical composition the connecting of humus substances is less intensive, their washing and removal deep inside substratum is intensified (look table 1 "Sand"). The creation of humus horizon is slower on clay substrata, but it provides relatively high humus content. The facts of mineralogical analyses show that in such substratum there is high content of minerals of montmorillonite group (badellit and other) which worsens the water-physical properties. The effectiveness of connection of humus substances is increased with carbonates (loess-like loam, marl rock, and chalk) increase in content of substratum. For example the humus content on chalk substratum in young soils can reach 10 % (look table 1). The disunity and the content of clay and sand material are the main soil forming qualities for the chalk substrate. "Pure" great block chalk is unfavorable substratum for soil formation. The investigations showed that increased content of mobile iron in soil also stimulates humus fixation. So soil formic potential of substratum greatly depends on its mineralogical composition. That’s why the grouping of mother rocks according to types made by us must be more individual.

Effective soil formation in the young ecosystems begins with the formation of sheltered plant communities in them. The study of regenerative phytocoenoses composition, and structure showed that they are rather advanced stages of regeneration zonal communities disturbed by anthropogenic influence. The course of successions was determined by functional control from the side of climax ecosystems. It speeded up regeneration processes in pedosystems too. With the age the forming phytocoenoses intensity their influence on substratum and at given stage of development display type specific soil forming ability completely. The largest distinctions are typical for herb and forest types of vegetation.

The first differs by greater quantity of annual leaf fall (750 - 850 g/m^2) 70 - 80 % of it come directly into the thickness of substratum as a result of roots dying (the roots in the layer of 0 - 15 sm. were taken into account). Forest communities bring nutritious elements back into soil less intensively, accumulating them in the increase wood parts. It typical for them the less quantity of leaf fall (to 480 g/m^2) coming on the soil surface and decaying slower than herb plant residues. In a view of indicated distinctions the herb phytocoenoses transform substrate deeper promoting accumulation in it humus dressed with nitrogen.

Forest communities of different types have different soil formic potential. Here the quantity and biochemical composition of coming leaf falls also play important role. Thus maple and linden forests according to its quantity (440 - 480 g/m^2) surpass oak forest (380 - 420 g/m^2). The maple-linden litter decay quicker it is evidently from its insignificant reserve: in October it’s less 1000 g/m^2), at the same time in oak forests it’s 1150 - 1570 g/m^2. The leaf fall of coniferous trees comes in even less quantity and decays slower than oak one. The young soil formation in different types of forest phytocoenoses shows completely these distinctions (look table1).

Decomposition of plant remains coming with leaf fall takes place at active participation of soil mesofauna. As it was shown by investigation of 55-year old ecosystems, earthworms are great significance for formations of humus horizon. At a present stage of young ecosystem formation their number is 60 - 70 % from climax level and the species feeding in the surface-soil (*Dendrobaena octaedra Sav.*, *Eisenia nordenskioldi Eisen, Lumbricus terrestris L.)* prevail. Nevertheless, at size of 80-100 representatives/m^2 earth worms promote more effective humification of litter, improve the soil structure. In ecotopes whit small number of *Lumbricidae* these soil indicators are worse. As it was established the peculiarities of phytocoenose are more important when earthworms settle substratum, than the qualities of mother rock. So the earth worms sometimes don't settle in coniferous ecosystems at all, and their number is lover in ecosystems with monotonous and rough leaf fall (oak forests) than in mixed communities. Perhaps it explains the fact that the soil formation is less effective in simple (monodominant) plant communities. Such representatives as *Diplopoda, Oniscoidae* take rather active part in transformation of litter in young forest ecosystems. Their size in broken ecosystems is restored quicker and achieves background level (8 - 15 representatives/m^2) for 55 years in comparing with earthworms.

Table 2. – Maximum speed of humus horizon formation for 50-60 years period (mm/year) in forest-steppe ecosystems with different substratum and plant conditions*

Type of substratum	Type of vegetation				
	Herb vegetation	Maple and linden forest	Oak forest	Asp forest	Pine forest
Sand	2.07±0.03	2.00±0.02	1.41±0.02	1.31±0.03	0.08±0.01
Loam	4.14±0.04	2.21±0.02	1.93±0.03	1.86±0.03	1.74±0.03
Clay	1.91±0.03	1.64±0.02	1.45±0.03	1.35±0.02	1.38±0.05
Marl	3.19±0.04	2.48±0.03	2.04±0.03	1.71±0.03	1.23±0.01
Chalk	1.43±0.03	2.04±0.03	1.89±0.03	1.61±0.02	0.53±0.03

*The rate of humus horizon formation is calculated taking into account of their equilibrium bulk density.

It is possible to examine the peculiarities of interaction of biota and substratum regarded from distinguished biolithocombination (look table 2) while appreciating the effectiveness of soil formation in young ecosystems according to the speed of humus horizon formation. The greatest soil formation speed evidently corresponds to the fullest realization of soil formic potential of environment in specific combinations of substratum-plant conditions. So in this way the SFPS of every distinguished type of substratum can be appreciated being influenced by different types of vegetation. On the other hand we can appreciate the SFPB of a definite type of phytocoenoses on different substrates. In soil restoration the most effective combinations of vegetation types and mother rocks are recommended for renaturation of anthropogenic disturbed soil. The choice of trend in restoration of ecosystems can be different depending on its specific aims. If it is necessary the most effective restoration of soil properties then the formation of grass phytocoenoses on exhibited substratum will be the best solution. The creation of forests including economic valuable tree species can be carried out with consideration of their adaptation possibilities and soil formic potential. The restoration of ecosystems on substrata with unfavorable edafotope qualities (sand, heavy clay, mining dumps of density rock) ought to be carried out in the trend of creation of tolerant biocoenoses providing the aesthetic rehabilitation of ecotopes and maintenance of biodiversity. It is necessary to take into account the objective laws of regeneration in nature ecosystems while forming ecosystems for renaturation. The qualities of exhibited mother rock should remain as a starting point.

4. Conclusions

1. Different types of substrata determine clear distinctions in efficacy of soil formation. Such characteristics as content of clay minerals and their qualitative composition, the content of carbonates, and ability to form structure are more important. The humus accumulation in the soil is determined besides substratum characteristics by quantity and quality composition of coming organic substance and by the type of plant community.

2. The studied types of plant communities have different soil forming potential depending on substratum characteristics. The more effective biota and substratum combinations are recommended for renaturation.

3. The increase of biodiversity stimulates the soil formation: complex polydominant communities ensure stable quick soil reproduction (to 4 mm/year)

4. Transformation of organic remnants into humus depends on the degree of soil fauna (*Lumbricidae, Diplopoda, Oniscoidea*) development. This indicator more depends on the type of plant community than on characteristics of substratum.

5. The formation of young ecosystems is under functional control of mature ecosystems of given natural zone which are the final stage of this formation. The soil formation in young ecosystems is going according to zone type.

6. Wholly the soil evolution in young ecosystems is a multivariate process and it can be governed by the creation of ecosystems with established characteristics beforehand.

References

1. Burikin, A. M., 1985, The rates of soil formation in technogenic landscapes in connection with their recultivation, Pochvovedenie, 2, pp. 81-93 (in Russian).

2. Yeterevskaya, L. V.; Lekhtsier, L. V.; Mikhnovskaya, A. D.; Lapta, E. I., 1985, Soil formation in technogenic landscapes on the loess rocks, Technogenic ecosystems. Organization and functioning, Novosibirsk, pp. 107-135 (in Russian).

3. Johnson, C.; Scousen, J., 1994 Mine soil properties of 15 abandoned mine soil sites in West Virginia, J. Environ. Qual., 24(4), pp. 635-643.

4. Hendrychova, M., 2008, Reclamation success in post-mining landscapes in the Czech Republic: A review of pedological and biological studies, Journal of Landscape Studies, 1, pp. 63-78.

5. Sheoran, V.; Sheoran, A. S.; and Poonia, P., 2010, Soil Reclamation of Abandoned Mine Land by Revegetation: A Review, International Journal of Soil, Sediment and Water, Vol. 3: Iss. 2, Art. 13., Available at: http://scholarworks.umass.edu/intljssw/vol3/iss2/13

6. Jenny, H., 1961, Derivation of state equations of soil and ecosystems, Soil. Sci. Soc Am. Proc., 25, pp. 385-388.

7. Shoba, S. A.; Gerasimova, M. I., Targulian, V. O., Urusevskaya, I. S.; Alyabina, I. O.; Makeyev, A. O., 1999, Soil formic potential of soil forming factors. Proceedings of the conference "Genesis, geography and ecology of soil", Lvov, pp. 90 -92 (in Russian).

8. Gennadiev, A. N., 1990, Soils and time: the models of development, Moscow, MSU, 232 p. (in Russian).

9. Targulian, V. O.; Krasilnikov, P. V., 2007. Soil system and pedogenic processes: Self-organization, time scales, and environmental significance, Catena, Vol. 71, Issue 3. – pp. 373-381.

10. Kleber, M; Sollins, P.; Sutton, R., 2007, A conceptual model of organo-mineral interactions in soils: self-assembly of organic molecular fragments into zonal structures on mineral surfaces, Biogeochemistry, 85, pp. 9-24.