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Research Article

The Dynamics of Primary Soil Formation and the Accompanying Processes Associated with it

VK Mukhomorov*, EI Ermakov, LM Anikina, OA Stepanova and TS Zvereva

Agropysical Institute, Grazhdansky Ave, Saint-Petersburg, Russia

***Corresponding Author:** VK Mukhomorov, Agropysical Institute, Grazhdansky Ave, Saint-Petersburg, Russia.

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Abstract

It was established that at long term year-round growing of plants (spring wheat and tomato) in adjustable conditions caused essential change in physical, chemical and biogenic properties of root-inhabited media accompanied by change in chemical elements content of plants, biochemical structure of organic substance and community of microorganisms. It was found that changes in root-inhabited medium on a number of attributes are similar to natural evolutionary processes proceeding the primary soil formation.

Keywords: Primary Soil Formation; Plants; Spring Wheat

Introduction

The knowledge of the fundamental laws of the transformation of the variety of interacting edaphic factors of the soil-plant complex is of considerable theoretical and applied interest. The unity and interrelation of objects and phenomena underlies the whole variety of soils and their evolution. The search for ways to restore the fertility of natural soils is possible only on the basis of identifying the fundamental laws governing the activity of biota and emerging organic matter, which transforms abiogenous rocks into soil-like bodies. Initially, lifeless mineral substrates are gradually colonized by a multitude of organisms, the number and composition of which changes during the intensive cultivation of plants. At the same time, multicomponent organic matter is formed in the root zone.

The controlled agroecosystem provides researchers with a unique opportunity to study the early stages of soil formation and the dynamics of the transformation of inert mineral rocks into a soil-like body under the influence of living matter. Very little information has been published on this issue. This paper also discusses the results of experiments on the dynamics of bioavailability and the dynamics of changes in the content of chemical elements in plant tissues. Currently, little is known about the dynamics of chemical elements from minerals to plant tissues during prolonged use of substrates. It is of interest to study the modification of minerals, the forming organic matter, the biotic community, the elemental chemical composition of plants during long-term and continuous exploitation of the mineral substrate. There are publications in which the need to study the dynamics of primary soil formation [1-4].

In addition, we investigated the relationship of the degradation of the chemical composition of the mineral substrate with the dynamics of changes in the content of chemical elements in plant tissues. This article presents temporal changes for multicomponent systems (chemical composition of plants and mineral substrates, biotic community, organic matter) at discrete points in time t = T, 2T,…, 23T, where T is the length of one growth period.

The root-habitat was granite rubble, which consisted of particles of 5-9 mm in size with a specific surface of 0.6 m^2/gram. The main mineral components of crushed granite is quartz, feldspar, mica, amphibole, chlorite and others. As is well known, the mineral substrate is initially hydrolytically alkaline. Therefore, before growing plants, the mineral substrate was subjected to neutralization. As a result, the acidity was established in the range of 5-6 pH, which is optimal for growing plants. Mineral substrates of controlled agrosystems are characterized by a higher density of living matter compared to soils. In small volumes, the roots of plants densely cover almost all particles of the mineral substrate. That is, the impact on the mineral substrate has a high density. The consequence of this is a high rate of change in the physicochemical properties of the mineralogical composition of rubble. At the end of each growing season, samples of granite rubble were taken to study the composition and properties of its surface, the composition and size of the microbial community, as well as the composition and quantity of organic matter.

The intensification of agricultural production and the associated deterioration of the environmental conditions highlights the urgent problem of improving the efficiency and sustainability of the functioning of agricultural systems. Achieving this goal is possible only with regard to the knowledge of the evolutionary scale of succession phenomena. This work is aimed at identifying the fundamental patterns in the system of root habitat - plants (RH-P) during primary pedogenesis under conditions of prolonged and intensive cultivation of plants on the originally abiogenic mineral medium (crushed granite). The experiment was performed under controlled conditions. Statistical analysis was performed using experimental results for all 23 vegetations. The details of the statistical analysis are presented in our monograph [5] and articles [6,7]. We found that during long-term (23 vegetations for 7.5 years), continuous and year-round use of the mineral substrate, processes occurring in it are similar in nature or are similar to natural primary soil formation processes associated with the transformation of abiogenic rocks into biogenic-inorganic soil-like bodies. These processes are accompanied by the formation of multicomponent organic matter and the development of a community of multi-species microorganisms in RH-P. Siete Cerros spring wheat and Ottawa-60 tomato varieties were grown year-round on the originally abiogenic mineral substrate for 23 vegetations (one growing cycle - 75 days).

Results and Discussion

After each growing season, we studied the multicomponent biochemical composition of organic matter, which was formed in RH-P system, as well as the types and numbers of the accompanying microbial community. The biochemical composition of the organic substance of the mineral substrate contained the following components: cellulose, hemicellulose, alkali-soluble and alcohol-benzene fractions, non-hydrolysable residue, as well as the water-soluble part (Table 1). In table 1, we present the results only for 1, 15 and 23 vegetations.

The number of vegetations	Total nitrogen, mg/100	Total organic carbon, mg/100	Water-soluble part	Alkali-soluble part	Hemicellulose	Cellulose	Alcohol-benzene part	Nonhydrolysable residue
Tomato								
1	2.0	20.0	1.5	2.5	15.2	43.4	2.0	34.6
15	11.3	112.1	1.0	10.9	7.4	13.2	6.4	60.8
23	31.7	247.3	0.5	34.1	3.2	5.1	2.4	54.4
Spring wheat								
1	1.8	29.7	1.1	6.3	9.6	39.4	2.1	41.2
15	11.9	90.9	1.2	26.5	7.1	12.3	5.6	48.6
23	32.1	260.4	0.6	36.1	2.4	6.8	2.4	52.1

Table 1: Dynamics of changes in the biochemical composition of organic matter (%) in the mineral root-inhabited medium.

Studies of the accumulation and transformation of organic matter had shown that these processes are similar to the processes of humus formation in natural soils. We note that the forming surface properties of solid minerals are in many respects similar to the properties of the organogenic horizons of dark gray forest soil. Thus, initially inert mineral substrates are transformed into bio-inert soil-like bodies. The change in the biochemical composition of organic matter (Table 1) convincingly demonstrated the processes of humification of organic matter during long-term cultivation of plants.

Microorganisms are an important factor that determines the sustainability of biological communities. V.I. Vernadsky [1] concluded that microorganisms are the strongest agents that transform the lithosphere. For example, fungi secrete a lot of organic acids. Organic acids contribute to the weathering of minerals. We also carried out microbiological studies that showed that when growing plants on a mineral substrate forms a microbial community: bacteria that use mineral nitrogen, bacteria that use organic nitrogen, spore-forming bacteria, cellulose-decomposing bacteria, fungi and actinomycetes. We have established that algae of four species (*Cyanophyta, Chlorophyta, Chrysophyta, Bacillariophyta*) developed on the mineral substrate. The dynamics of the formation of the microbiotic community are shown in table 2. Thus the initially lifeless mineral substrates are gradually colonized by microorganisms. At the same time, the process of formation of multicomponent organic matter is carried out. The main mechanisms of action of microorganisms on minerals are acid and alkaline hydrolysis, complexation, oxidation and reduction.

We have analyzed the dynamics of the mineralogical composition of the initially crushed granite and the mineralogical composition of crushed granite after growing plants after 12 vegetations. The table 3 demonstrates dynamics of the particle size distribution composition of the originally crushed granite and after growing plants for 12 vegetations.

Cultivation of plants on the mineral substrate leads to the grinding of mineral granules. A comparison of experimental data shows that wheat is a more aggressive weathering agent than the tomato. The data in Table 3 also demonstrate the effect of nutrient weathering of minerals, which is accompanied by an increase in fine earth. In all fractions of the experiment, the washout from the roots contained less quartz than in the initial granules of the min-

The number of vegetations	Bacteria that use mineral nitrogen	Bacteria that use organic nitrogen	Spore-forming bacteria	Cellulose-fermenting bacteria	Fungi	Actino-mycetes
Tomato						
1	10800.0	6700.0	5.1	0.6	4.5	-
15	698.7	1073.6	51.1	1.7	46.0	105.6
23	3905.3	3101.0	135.0	1.0	10.2	27.2
Spring wheat						
1	740.0	530.0	4.2	2.1	7.8	-
15	807.6	1200.8	26.9	2.0	66.9	36.0
23	6991.2	5416.9	127.6	2.2	19.0	76.9

Table 2: Dynamics of change in the number of microorganisms of the root environment (in thousands per gram of dry mineral substrate).

Fraction content, %.				
Размер гранул				
9 - 5 mm	5 - 2 mm	2 - 0.25 mm	< 0.25 mm	Total, %
Initial crushed granite				
95.45	3.89	0.50	0.09	99.96
Crushed granite after 12 vegetations of tomato cultivation				
89.62	8.25	1.42	0.73	100.02
Crushed granite after 12 vegetations of spring wheat				
88.18	8.63	2.54	0.64	99.99

Table 3: Dynamics of the particle size distribution composition of crushed granite (dry screening).

eral substrate. At the same time, the content of potassium feldspar is reduced for all fractions. In the process of using granite rubble, granulation of kalifeldshpat granules takes place. These minerals have high hardness (6-6.5 on the Mohs scale).

Long – term continuous cultivation of plants on the mineral substrate is accompanied by a decrease in the ash content in the plant organs of tomato and wheat (Table 4).

The number of vegetations	Tomato			
	Fruits	Roots	Leaves	Stems
1	11.6	33.8	26.1	14.5
15	13.1	19.7	22.9	19.4
23	13.4	19.5	24.8	20.1
	Spring wheat			
	Grains	Roots	Leaves [*)]	Stems
1	3.3	42.4	-	17.4
15	2.7	22.1	-	16.9
23	2.8	21.4	-	15.7

Table 4: Ash content (% by dry weight) in tomato and wheat plants.

[*)] The experiment was not performed.

Plant roots are most saturated with mineral elements. We note that the maximum amount of ash corresponds to the initial vegetations. This is probably due to the intense primary weathering of the mineral substrate. Intensive formation of organic matter and its transformation contribute to the formation of organic-mineral films on the surfaces of the substrate, which block the weathering of mineral particles. The result of biogenic weathering of minerals is the grinding of rock, leaching of ash elements, the transformation of mineral granules into fine earth, the adsorption of organic substances on the surface of minerals, the formation of humates, fulvates and their complexes with metals. Plant roots play an important role in these processes. The root systems of plants and their excretion affect the surface of the mineral particles. This effect leads to the fact that on the surface of the minerals keep traces of the effects of the roots. Thus, the mineral substrate is subjected to intensive biotic weathering. The accumulation of the fine fraction of the mineral rubble, which actively interacts with the nutrient solution elements and metabolites of soil microorganisms, is accompanied by the formation of some secondary minerals.

V.I. Vernadsky [8] and other researchers marked close interrelation between elemental chemical structure of plants and grounds on which plants grow. We do not present here data on the evolutionary dynamics of the content of chemical elements of plants. We have analyzed in the article [9] the evolutionary dynamics of the content of chemical elements (P_2O_5, SO_3, CaO, MgO, Na_2O, K_2O, Fe_2O_3, SiO_2, Al_2O_3, MnO, TiO_2) in plants. In this study, we searched for certain quantitative relationships in the degree of diversity of the soil - plant systems in agroecosystem and analyzed its effects on plant functions.. As our studies have shown, the distribution of chemical elements in plant organs is interrelated. Moreover, there are causal relationships between the diversity of the content of chemical elements in plant organs and the diversity of the microbial community and organic matter in RH-P systems [9]. The causal relationship between the state of organic matter forming in mineral RH-P systemsand stage of dynamics of the microbiotic community is not only of scientific interest but also of practical value and is an important information factor of the dynamic RH-P systems related to the production potential of plants. For example, plant productivity is defined not only with a diversity of subsystems (organic matter and microbiota), but mainly of streams of the information between them [10].

Conclusion

Prolonged reuse of mineral substrates had shown that minerals undergo significant changes due to the development of the initial stages of the primary soil-forming process. The above studies allowed us to identify a number of previously unknown features of the interaction of living and inert substances, thereby expanding the generally accepted views on primary soil formation. The results obtained provide an opportunity to take a fresh look at the ecological integrity of the biosphere, and also draw attention to new nontrivial patterns.

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