Agroecological assessment and efficiency of potential fertility

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Abstract. The paper raises the issues of biosphere development, which is carried out against the background of complex processes of substance and energy exchange. Under the influence of V.I. Based on Vernadsky's ideas, major progress was made in studying the movement of chemical elements and redistribution of matter within different parts of the biosphere. The energy of soil formation is a new scientific direction, studying on the basis of system analysis the regularities of transformation of solar energy spent on soil formation (physical and chemical destruction of soil-forming rocks, hyper gene transformation of minerals, etc.), revealing objective ecological conditions of formation and distribution of soils and biogeocenosis in the biosphere. An important task of soil formation energy is the development of effective technological systems to increase the full utilization of solar energy, to create highly productive natural and agricultural biocenoses. Before outlining the main directions of soil formation energetics, it is necessary to define a set of issues that are relevant to this problem. They should include sources and expenditures of energy in soil formation, the amount of energy accumulated in the soil, and others. Much less attention is paid to the energy assessment of these processes. Meanwhile, cognition of the regularities of energy exchange and transformation in the biosphere is a very important problem of modern natural science. From the energy point of view, the emergence and development of the biosphere on Earth should be considered as a grandiose process of gradual accumulation of the stock of convertible solar energy in the surface layer of the planet.

1 Introduction

Many scientists [1, 2, 3] were the first to give a multilateral assessment of the energy cycle and redistribution on the land surface, from the tundra to the tropics. They laid the foundations of a new scientific direction - the energy of soil formation. The source of soil formation energy is solar energy reaching the Earth's surface and defined as the radiation balance of the Earth's surface.

The energy of solar radiation reaching the upper layers of the Earth's atmosphere is determined by the solar constant, estimated at an average value of 1.94 cal/cm^2 min. Approximately half of it is directly reflected by the atmosphere and the earth's surface,

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while the rest is transformed into energy used mainly for soil formation. The quality of heat coming from inside the globe to the soil surface is very small compared to the solar heat (about 55 cal/cm^2) and is practically not taken into account in calculations.

Soil like biogeocenosis is generally formed by the interaction of energy fluxes expended on: I) evaporation and transpiration; 2) biological processes (including microbiological, enzymatic, humus formation, etc.); 3) hypergenic transformation of minerals; 4) transport of substances with filtered soil water.

2 Rationale for the purpose and objective

A number of scientists have dealt with this problem and it was [2] found that the main part of energy (from 95 to 99.5%) is spent on evaporation and transpiration. Expenditures on biological processes account for 0.5 to 5% of the total energy. Hypergene transformation of minerals consumes hundredths and thousandths of a percent of all energy. Energy expenditure is minimal under low-thermal conditions. For example, in biogeocenosis of tundras and deserts energy consumption is 2-5 kcal/cm^2 per year. With increasing radiation balance, the amount of energy consumption increases to 10-40 kcal/cm^2 per year in forests and steppes of temperate climates and reaches a maximum of 60-70 kcal/cm^2 per year in biogeocenosis of humid tropics. Simultaneously with the general growth of energy expenditures, the energy accumulated in the annual growth of plant mass increases. This dependence can serve to assess the full utilization of radiation and water resources for forcing productivity of biogeocenosis. It is not surprising that qualitative transitions of combinations of incoming energy and atmospheric moisture were outlined according to the change of habitats of the main soil types.

Research methods. According to the results of research [3], using the hydrothermal system with coordinates; radiation balance R, annual precipitation sum P, indices of effective moistening Kp and hydroid, revealed objective natural conditions of existence of different biogeocenosis and their corresponding soils, as well as their spatial distribution. The main source of energy for all processes occurring in the biosphere is radiation energy. However, its realization is possible under certain water supply. Therefore, the boundaries of zonal soil types are strictly determined by the ratios of incoming energy and the degree of moistening. At the same radiation balance different biogeocenosis can exist, which can have zonal distribution. In this case, the transition from one zone to another occurs when the amount of water involved in the moisture exchange process changes.

The hydrothermal system objectively reflects the most general relations of the main energy flows in the biosphere, and it is reasonable to use it as a basis for soil-genetic ecosystem studies. The use of energy approaches allowed to reveal a number of new regular relationships in the multicomponent system of biogeocenosis - between its atmospheric, biological and mineral components - and made it possible to quantitatively characterize these relationships.

The foundations of a new scientific direction, biogeoenergetics of soils, have been established [4, 5]. Biogeoenergetics investigates the regularities of transformation and consumption of solar energy for the formation of highly productive natural and agricultural cenoses, biomass of microorganisms and soil zoofauna, humus formation, organomineral formation, enzymatic processes, redox processes, and others. It allows to reveal new, previously unknown sides of energy exchange in the complex microbiological and enzymatic processes of transformation of organic matter and mineral part occurring in the soil with the use of solar energy to increase the productivity of agrobiogeocenosis. Soil accumulates a huge amount of energy in the form of soil humus, plant residues and microbial mass. This energy, being involved in the grandiose in scale and importance of the

biological cycle of substances and energy, affects the nature and intensity of biological processes occurring in the soil.

The rational use of solar radiation and energy accumulated in the organic matter of soils to increase the productivity of plant associations and cultivated plants, the study of the regularities of the energy cycle in the system soil - microorganisms - plants is important.

The main task of soil scientists is to put into service the solar energy accumulated in the soil and the huge flow of solar radiation coming to the surface of the earth. The use of solar radiation by biogeocenosis is as follows. Every year on the surface of the Earth falls 3-I0^{24} J of energy from solar radiation. Of this energy, approximately about 0.1% (3x10^{21} J), and only 0.001% is used as a niche, or I.5x10^{19} J. The consumption of all types of energy amounted to 3x1020 J, or 0.01% of the total amount of solar energy falling on the Earth. Plants are the primary bioenergetic link of ecosystems, incorporating through photosynthesis the electromagnetic energy of solar radiation into life processes. Radiation from the Sun arises from the continuous transformation of hydrogen into helium. Almost all energy used by mankind is based on solar energy stored in the process of photosynthesis, which is the primary source of existence, prosperity and development of life on Earth in all its complexity, diversity and beauty. According to V.I. Vernadsky [6, 7], the biosphere can be considered as an area of the Earth's crust occupied by transformers that convert cosmic radiation into bound energy. Such highly organized bio transformers of solar energy on our planet are biogeocenosis. The annual production of various ecosystems on the Earth's surface amounts to 52.9 billion tons of organic matter and binds about 21.3-I0^{16} kcal of solar energy. The energy equivalent of phytomass varies: in the range of 4.1-4.5 kcal per I g of plant mass. At the same time, photosynthesis consumes less than 0.1% of all solar energy coming to the Earth's surface.

On the basis of data on the heat of combustion of various plant groups, on annual growth and total biomass of vegetation, taking into account the distribution of annual values of total radiation, the regularities of solar radiation utilization and energy reserves associated with the biomass of plant communities have been established.

Productivity of phytomass, full utilization of radiation energy and energy expenditures for soil formation consistently increase with increasing relative moisture content (Table 1).

To obtain high yields, along with solar radiation, the most important factors are the creation of optimal soil water regime and application of a number of techniques that promote more rational use of moisture for productive photosynthesis and reduction of transpiration coefficient. Creation of permanent sources of supplying plants with sufficient amount of carbon dioxide through organic fertilizers, application of mineral fertilizers and growth stimulants favors rational use of irrigated water, reduction of water consumption for crop yield formation, which is of great importance in arid regions.

Table 1. Full utilization of radiation resources *(a)* and energy inputs for soil formation *(Q)*

Soils	Plant communities	Radiation balance R *kcal/cm^2, year*	Precipitation, P, *mm/year*	Relative humidity, *Kp*	Full utilization of radiation energy, *a*	Energy inputs for soil formation *Q, kcal/cm^2,* year
Mountain-meadow peat	Alpine meadows	25-30	600-800	1.70	0.74	18-22
Mountain-meadow sod	Subalpine meadows	30-35	600-800	1.38	1.38	21-25
Chernozems	Variegated steppes	35-40	450-550	0.84	0.84	20-23
Sulfur-meadow and grassland	Lowland meadows	45-50	250-300	0.46	0.46	16-18

The nature and intensity of biological processes in soil are related to the reserves of the radiant energy of the Sun, which, accumulating in the plant mass and in soil humus, serves as an irreplaceable source of energy for the vital activity of microorganisms and various biological and mineral transformations. To understand and manage soil processes, it is extremely important to take into account the total amount of energy accumulated in soil organic matter and regulate its balance.

According to the data of humus fractional composition and energy indices of its separate fractions, the heat of combustion of 1 g of humus and the total amount of energy accumulated in humus of different soils are calculated. These energy criteria are useful for soil diagnostics and in-depth consideration of soils in genetic terms.

Table 2. Combustion heat of different fractions of humus acids of soils, cal/g

Soil	Alcohol-benzene fraction	Humic acids	Fulvic acids	Non-hydrolyzable residue (humins)
Mountain-meadow sod	8480 on average	4640	2200 (1520-2790) on average	4510
Mountain chernozem		4510		4200
Meadow		4830		4050

Calorimetric methods are relatively labor-intensive, so the calorific value of humus acids is determined by calculation.

According to the data of soil scientists and researchers [8, 9], for the land of the globe, humus reserves are as follows $2{,}2x10^{12}$t energized $12xI0^{18}$ kcal, while the total land biomass (including humus, litter, higher plants, microorganisms, etc.) is equal to $5.5x10^{12}$t dry organic matter with energy content $27.5x10^{18}$ kcal, i.e., about 50% of the biomass and energy reserves of the land are humus substances. All this shows, as V.A. Kovda notes, that the humus shell on the Earth is a powerful geochemical accumulator of converted solar energy, an accumulator of universal planetary geological scales. To determine the bioenergetic indicators of humus, a methodology was developed to determine the heat of combustion of humus acids (alcohol-benzene fraction, humic acids, fulvic acids, humins) isolated from different soils [10].

It was found that the heat of combustion of humic acids in mountain-meadow soil is 4640 cal/g, in chernozem it decreases to 4510 cal/g, while in chestnut soil and especially in gray soil it increases to the maximum values - 5100-5290 cal/g. The heat of combustion of humins is somewhat lower. The heat of combustion of fulvic acids varies within 1520-2790 cal/g (average 2,200 cal/g). High values were obtained for the heat of combustion of the alcohol-benzene fraction of humus - 8480 cal/g (Table 2).

High values of potential energy in humic acids of sulfuric and chestnut soils are explained by their richness in nitrogenous, protein compounds of microbial plasma.

3 Results

The problem of energetics of microbiological processes, in the field of energetics of microbiological processes, only some questions are covered. When studying the amount of energy accumulated by microorganisms in soil, there were methodological difficulties in determining the total number of microorganisms in soil and their average mass. The determination of the number of microorganisms was carried out by the direct counting method of S.N. Vinogradsky. Based on the studies of bacterial mass, the average live mass of a billion bacteria we took 0.5 mg (dry mass 0.1 mg). The mass of microscopic fungi and actinomycetes is equal to 5-10% of the mass of bacteria. According to the average mass of

microbes and the total number of bacteria, the biomass of microorganisms in the soil was calculated. It was found that the biomass of microorganisms in the 0-25 cm layer of the studied soils varies within 185-250 g/cm^2, of which bacteria account for 172-235 g/cm^2, and actinomycetes and fungi 13-21 g/cm^2. The content of microbial mass in the composition of humus is 0.9-3.5% and significantly affects the energy nature of humus acids.

Table 3. Microbial mass and amount of cohesive energy in soil (in 0-25 cm layer)

Soil	Number of microorganisms, mln/g soil	Bacteria		Actinomycetes and fungi		Total		Microbial mass, % to humus	Energy used for microbial mass formation, kcal/m^2
		g/m^2	ccal/m^2	g/m^2	ccal/m^2	g/m^2	ccal/m^2		
Chernozem	7800	235	1460	15	80	250	1540	0.9	40500
Brown post-forest	6940	219	1360	14	70	233	1430	1.1	37600
Chestnut	5410	172	1401	13	70	185	1210	1.4	31700
Serozemic	6680	208	1290	21	110	229	1400	3.5	37000
Meadow	7240	194	1200	18	90	212	1290	1.3	34000

Using indices of specific heat of combustion of mass of different groups of microorganisms. obtained by burning microorganisms in calorimetric bomb (for fungi 4900-5100, actinomycetes 5700-5800: bacteria 6200 cal/g), we determined the amount of energy bound in the microbial mass of the studied soils (Table 3). It should be noted a significant amount of energy in the microbial mass of gray soil [11, 12].

4 Conclusions

Based on the studies conducted in this area, it follows that the energy balance of biological processes, provided for the study of the energy balance of biological processes, the determination of the biomass of various components of biogeocenosis and the solar energy accumulated by them is of primary importance. The energy balance of soil organic matter transformation is of theoretical interest and practical significance. Thus, according to M.M. Kononova, in the study of plant residues entering the soil and their humification, and should not be left the question of the energy of the humification process. The data on energy changes of plant mass as a result of its humification and new formation of humus substances, on the value of humification coefficient and mineralization coefficient and soil humus are quite insufficient to perform balance calculations of energy of transformation of soil organic matter. In an ecosystem with favorable conditions for the accumulation of plant matter and their humification, slowed down processes of humus mineralization, a positive balance of energy humus accumulation is created (for example, in chernozems and brown subforest soils). Depending on the intensity of energy flow in the soil as a result of plant matter input and humus mineralization, balanced positive and negative energy balance of humus accumulation should be distinguished.

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