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INSTRUMENTS AND METHODS TO DETERMINE CHARACTERISTICS OF HEAT, MOISTURE AND WATER SOLUBLE COMPOUNDS TRANSFER IN SOILS

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Abstract. A complex of techniques and methodics to investigate heat, moisture and water soluble peat soils compounds transfer characteristics has been described. Water-physical characteristics and characteristics of peat soils heat and mass transfer of Belarus and Poland have been provided. The characteristics obtained may be used to prognosticate and optimize temperature and moisture and peat soils saline regimes.

Keywords: peat soils, instruments, physical and chemical properties.

INTRODUCTION

Temperature and moisture levels, structural parameters, as well as the content of various water soluble compounds in porous moisture determine main peat systems and soil features. Due to daily temperature and moisture fluctuations, precipitations fallout, freezing and melting processes, filtration of melting waters in the top soil layer in natural conditions, temperature and moisture level variations, as well as structural transformations occur continuously.

To manage natural peat resources efficiently and to protect environment, one needs reliable temperature and moisture modes, structural parameters and water soluble compounds concentration forecast in the upper peat system and soil layer. Physical-chemical factors responsible for transformations in the water-physical peat soil properties in the process of natural evolution and under anthropogenic must be studied.

Peat soils, though potentially fertile, show serious unsatisfactory water-physical and heat features, stipulating quite unfavourable situation to cultivate agrophytocenosis. Their fertility increase can be achieved by the physically substantiated methods for water-air and heat modes optimisation. This task can practically be solved with the help of various melioration types. Then undertaking water-and heat-control, it is necessary to know water-physical and heat features of the meliorated lands and the methods for the calculation of initial properties degree of changes during cultivation.

To forecast heat-and mass transfer processes, mathematical models are applied at different levels, starting from the regression and ending with deterministic ones depending on the tasks and targets set forth. Please note, that for the forecast of current and expected technogenic changes in natural-territorial complexes, regression models require large-scale and long-term observations, which lose their reliability when the formed natural heat and mass exchange conditions are broken. Besides, spatial-temporary dependence of the parameters calculated is usually expressed by the non-linear complex functions, that do not allow to apply primary regression equations. Processes of heat, moisture and water soluable compounds transfer and the structure transformation in natural dispersed systems are described more completely using a heat and mass transfer equation system. Modern theory of mass and heat transfer in natural dispersed systems is based on the thermodynamics of irreversible processes and the physics and chemistry of surface phenomena. The methodology of heat and mass transfer theory is specific with close-fitting combination of the calculation methods for temperature and mass fields that apply differential equations of transfer and experimental transfer in feature identification methods.

Please note, that when mathematical modelling of heat, moisture and chemical element transfer in soils is applied the problem is caused not by the decisions of heat-mass transfer equation system, but by the lack of sufficient data to reveal its parameters.

METHODS

Mathematical models of internal heat-mass transfer in the layer of soil have been developed for various surface border conditions, that allow to calculate freezing and melting processes, moisture and water soluble compound transfer, transformation of structure of various organogenic and mineral systems. Techniques and instruments were designed to determine characteristics of heat-mass transfer and soil formation at various regimes. The studies carried out revealed substantial mutual impact of heat, moisture, water soluble compound processes on one another. That is why to achieve reliable forecast for these processes, it is expedient to consider their conjugation and to solve the problems as a complex. Modern PC facilities with modern programmes available allow for processing of complex data on the characteristics of internal heat-mass peat systems and soils transfer together with external heat-mass exchange parameters taking into consideration meteorological factors.

Some devices and methods to determine heat, moisture and water soluble soil compound transfer should be viewed in more details.

To study thermal-dynamic water characteristics in soils, and to prepare samples by vacuum-sublimation drying in order to investigate their structure, a thermostatic vacuum chamber (Fig. 1), consisting of a thermostatic system sample heating, temperature check, vacuum chamber and water steam pressure test were used. By means of the above isotherms of water desorption in various organogenic systems were plotted. The methods of quick sample freezing under predetermined moisture content was worked out together with vacuum sublimation of ice which allowed to fix and research organo-mineral soil skeleton structures at various moisture levels. To measure capillary moisture potential of soil samples in the laboratory and field conditions, an extensiometer (tensiometer) was designed. The tensiometer lay-out is shown in Fig. 2. A glass body 1 is heated by a brass heater 2. A porous ferrule-probe 3 is fixed at other side. Inside there is a pressure gauge in the form of a glass capillary 4; its lower end fixed on the rubber-band pressure sensor 5, and the upper end is soldered. The lower part of the capillary is filled with working liquid 7, and the upper end with air and water vapour. Inside the capillary there is hair with removed fat 6, which prevents a breakup of the working liquid column under sharp swings of the pressure measured. As a working liquid, gas-free distilled water is used. To make tensiometer suitable and ready to use quickly a brass connector 8 is fixed at the reverse side of the probe ferrule, in which a plug 10 is screwed through the watertight living 9.

To prepare the device to work, it is necessary to screw out the plug 10 and to fill the probe with distilled water 11. To take measurements the probe must be completely sunk into the material which moisture potential is to be deteremined. Due to the water-saturated walls of the porous ferrule, moisture and water filling the device up, are connected with each other and can move towards lower potential. Accordingly, water pressure on the rubber-band 5 will change, and as a result the height of liquid column in the capillary and the length of vapour-air part of the capillary, which is used to evaluate capillary potential of moisture in the material on the scale 12 are shown. Measuring time depends on the studied material moisture content and is 15-60 min.

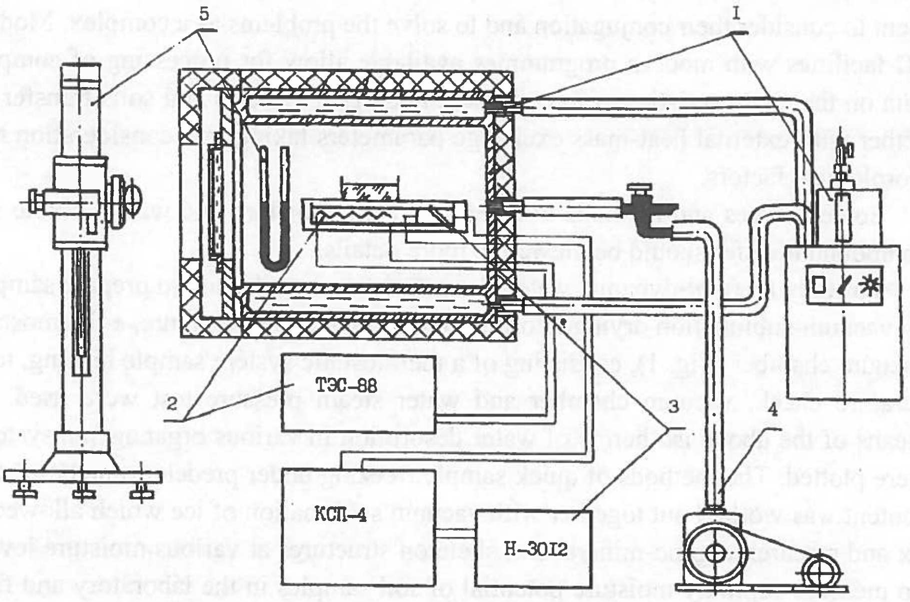

Fig. 1. Vacuum thermostatic chamber.

To determine the temperature of water freezing starting point in soils and soil solutions, a kit presented in Fig. 3 has been developed. It consists of a massive metal body with a lid 1 where cassettes for the material under investigation 2 are placed. In the lower cassette measuring elements are placed. They register sample temperature 3. Zero temperature sensors are moved out into a cartridge case in the lower part of the body. The whole installation is placed in a heat-insulated body made of hard foam plastic 5. In the lower heat insulated part a vessel with melting ice 6 is located. Zero temperature sensors are placed in it. The principle function is based on the registration of the dynamics of temperature changes in the sample studied in the course of its cooling. Water supercooling within the course of freezing is reduced to the minimum due to the application of crystallisation initiators 7.

Registering instruments may be both numerical and self-recording volt-meters, that allow to register a signal of a level not lower than 1 mkV. Using this installation, it is possible to determine the temperature of freezing point in the soils with the accuracy of 0.005 °C depending on their moisture content and concentration in the porous solution of water soluble compounds that allow to obtain unfrozen water amount related to the temperature in the soil and to assess osmotic potential of porous solution.

A device designed for the assessment of coefficients of soils heat conductivity is presented in Fig. 4. Its basic elements are heat exchangers of duralumin D-16 7 and

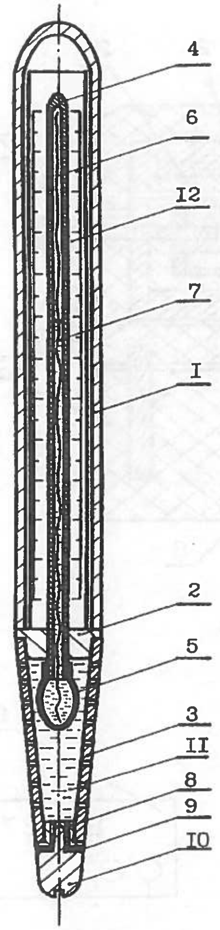

Fig. 2. Tensometer scheme.

2 of flat disc. Special sensors of heat flow are mounted in heat exchangers as well as a top and bottom temperature difference sensor 6 of heat exchangers. The top heat exchanger 7 is in heat contact with the air heat-sink, and the bottom one 2 contacts with wire heater 1. The surface of lateral heat exchangers, as well as the bottom part of the heat exchanger 2 are protected with the acrylic plastic heat insulator 4. Between the heat exchangers there is a cassette 5, filled with the studied sample 3. The cassette consists of 2 parts and can move apart vertically. That allows to achieve a good contact of heat exchangers with the material studied, and subject the sample to various mechanical loads.

For heat insulation of the external surface of the cassette there is a ring from deforming material (flexible polyurethane or foam polyurethane). On the lateral surface of acrylic plastic heat insulator of the bottom heat exchanger there is a detachable handle with a clipping screw 10 and deformation indicator of C1-10 type 11.

The registration of sensor signals of heat flow and the difference in temperature, as well as electrical supply to the heater is carried out by serial instruments: numerical vtvm B 7-21 (12) and direct current source B 5-49 (13).

By means of this device it is possible to determine coefficients of soil heat conductivity in thawing and frozen condition at various moisture contents and compacting loads.

In the laboratory of physical-chemical engineering of natural dispersed systems there is also an adiobatic calorimeter, by means of which it is possible to determine efficient soil heat capacity in thawing and frozen state, as well as the relation between the unfrozen water amount and temperature; the devices and methods to study diffusion coefficients of moisture in thawing and frozen states in soils were developed. One should note that the relation between the amount of unfrozen water and temperature specifies not only soil features in the frozen state, but is a significant thermal-dynamic feature of bound water in the soil at positive temperatures.

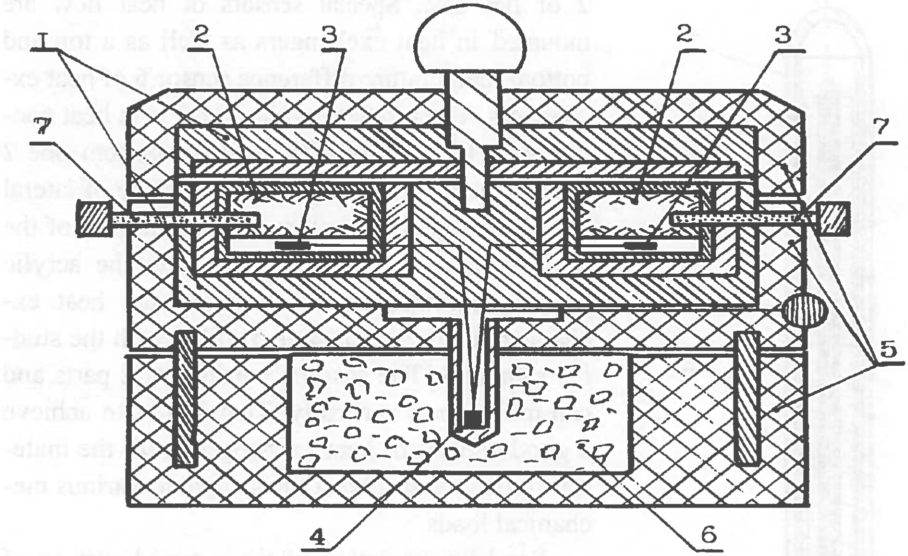

Fig. 3. Device to determine the water freez start in soils, and solutions.

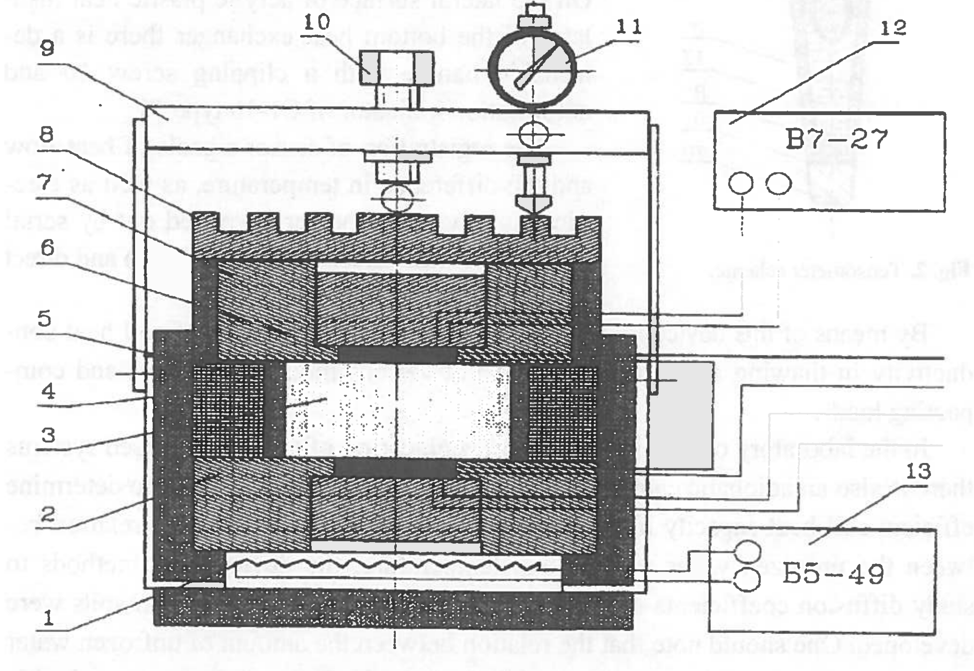

Fig. 4. Device to identify soils heat conductivity coefficients.

RESULTS

At present the issues related to mineral water soluble compound transfer in soils gain even greater significance. It is evident that moisture in natural dispersed systems is a complex solution of mineral and organic compounds. Under the impact of mass exchange processes (diffusion, thermal-moisture exchange, evaporation, precipitations, infiltration, etc.) the natural dispersed systems, of composition of porous solution varies continuously. Water-soluable compounds transfer in natural dispersed systems determines the regimes of plants mineral nutrition. The transfer of water-soluable matters also refers to such ecological problems as upper soil-ground layer contamination with chemical production wastes and radioactive materials. The transfer of water-soluable compounds in natural dispersed systems is a highly problematic phenomenon in its mathematical description and experimental research. It is known, that water-soluable compounds in natural dispersed systems are both in porous phase and bound with solid phase material. The correlation between these forms may vary under the impact of various factors: solution concentration, ambient pH, temperature, material moisture content. The water-soluable compounds transfer occurs mainly in two ways: by diffusion due to gradient concentration and by convection due to moisture. To quantitatively describe water-soluable compounds, it is expedient to define constants of the balance: hard phase - solution, diffusion coefficients of water-soluable compounds and moisture transfer characteristics. The study of this phenomena and their mechanism calls for quantitative assessment on the background of overall matter transfer. It is the basis for the development of methods for the control of active migration porous solution compounds.

Radionuclides transfer, as well as other sorbing water-soluable compounds in natural dispersed systems can generally be described by the following equations:

$$\frac{\partial C1}{\partial t} = D_{\text{ps}} \frac{\partial^2 C1}{\partial x^2} - V \frac{\partial C1}{\partial t} + \frac{\alpha}{W}\left(\frac{1}{K_{\text{d}}} C2 - C1\right) \qquad (1)$$

$$\frac{\partial C2}{\partial t} = -\alpha\left(\frac{1}{K_{\text{d}}} C2 - C1\right) \qquad (2)$$

where: C1 - a radionuclide concentration in a porous solution; C2 - a radionuclide concentration in a system solid phase; D_{ps} - a radionuclide diffusion coefficient in a porous solution; V - linear velocity of a convective moisture transfer; K_{d} - distribution coefficient, characterising radionuclides correlation linked to the material solid phase and located in porous solution; α - a radionuclide mass exchange coefficient in the material solid phase - porous solution system; W - a material moisture content.

With sufficiently high mass exchange coefficients and small velocity levels convective moisture transfer V, radionuclides migration can be expressed by the following equation:

$$\frac{\partial C1}{\partial t} = \frac{D_{ps}}{\left(1+\frac{K_d}{W}\right)} \frac{\partial^2 C1}{\partial x^2} - \frac{V}{\left(1+\frac{K_d}{W}\right)} \frac{\partial C1}{\partial t}. \qquad (3)$$

Complex of parameters, placed before the second concentration derived as a coordinate, defines an actual velocity of diffusion processes and corresponds to the efficient radionuclides diffusion coefficient:

$$D_{ef} = D_{ps}/(K_d/W+1). \qquad (4)$$

The radionuclide diffusion coefficient D_{ps}, put in the Eq. (4), depends mainly on such factors as radionuclide diffusion factor in a volumetric solution and the porous space geometry. Thus we can express D_{ps} as:

$$D_{ps} = D_o K_c \qquad (5)$$

where: D_o - radionuclide diffusion coefficient in a volumetric solution; K_c - liquid phase communication coefficient.

Considering (5), the radionuclides diffusion efficient in a dispersed environment can be presented as:

$$D_{ef} = D_o K_c/(K_d/W+1) \qquad (6)$$

The formula (6), reflecting multifactorial character of D_{ef} relation, allows for the optimum way of planning out an experiment on the determination of the effective diffusion coefficient against concentration and moisture content. Diffusion coefficients in a solution for the majority of kations and anions are known at present and their values are given in the reference literature. The relation between K_c and W, as a rule, is of a monotonous character. The maximum K_c (W) value can be much lover than a unit, and becomes equal to a zero under the water film breakup in a material.

Hence, such coefficients as distribution K_d, mass exchange α, a radionuclide diffusion in a porous solution D_{ps}, diffusion course curving K_c pertain to the basic characteristics of radionuclides transfer and exchange.

By methods of mathematical modelling and experimental studies we found out that under small velocity of a radionuclide transition, solution - solid phase in the system of two contacting plates with varying initial radionuclides concentrations, a substantial difference of the distribution coefficients K_d in donor and acceptor areas is observed. This difference vary in time close to the exponential, and depends, basically, on mass exchange coefficient. Due to this factor, a complex technique of D_{ps}, K_d and α determination was developed. The technique was described in detail in the appendix to the report on the “Forecast and Regulation of Water-soluable Compound Transfer in Natural Dispersed Systems” in 1995, state registration N 1993182. The coefficients of distribution and diffusion of cations of alkaline and alkaline - land metals have been determined by it, as well as radionuclides Cs-137 and Sr-90 in typical examples of peat, clay and sandy soils.

Using the devices and methods described above a full characteristics of internal heat- and moisture transfer of various organogenic rocks and peat soils was determined (Figs 5-7).

In Table 1 there is data on the distribution coefficients and efficient diffusion of Cs-137 and Sr-90 in the soil samples with various mineralization degree and hydrophylity, selected at the Polessye test-melioration station.

As it can be seen from the data, basically ash content increase and water-retaining ability reduction of peat soil samples, is related to the reduction of Cs-137 distribution coefficient. Thus, the proportion of the maximum to minimum distribution coefficient exceeds 10. At the same time, in the peat soils samples of closer mineralisation values but selected from different sites, the diffe-rence can be observed in Cs-137 distribution coefficients, that, is probably stipulated by the impact of the exchange complex on the distribution coefficients and the difference in the material sample composition at various sites.

In the case of Sr-90 with the degree of mineralization change from 3 to 29%, no essential distribution coefficients occur. With the increase in mineralization degree to 66% a sharp increase of distribution coefficient of Sr-90 from 60 to 7 occurs. Comparing Cs-137 and Sr-90 distribution coefficients in various samples, it is evident that Cs-137 distribution coefficients are 3-9 times higher than Sr-90.

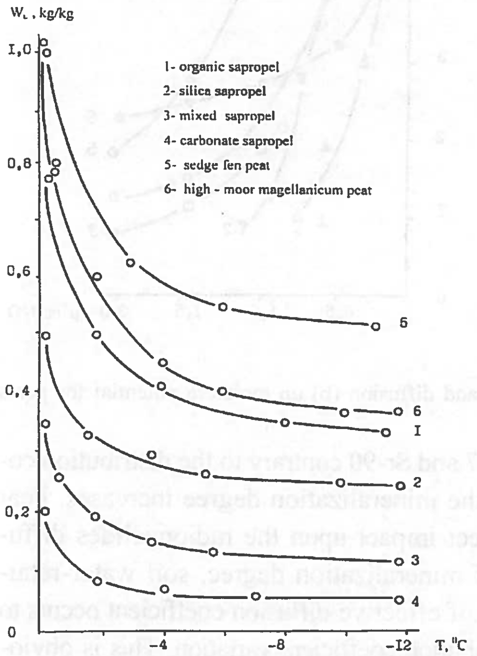

Fig. 5. Dependence of unfrozen water amount on the temperature for organogenic systems.

Table 1. Distribution coefficients and efficient diffusion coefficients in peat soils with various mineralization degree

Sample No.	A_{sh} %	U_{phch} kg kg^{-1}	Cs-137 K_d	Cs-137 $D_{ef}\,10^{12}$ m^2 c^{-1}	Sr-90 K_d	Sr-90 $D_{ef}\,10^{12}$ m^2 c^{-1}
1	25.1	0.30	98	4.2	20	10.4
2	66.4	0.14	52	2.0	7	12.0
3	22.7	0.33	290	0.93	62	4.2
4	29.3	0.33	166	1.5	60	3.2
5	23.5	0.32	366	0.6	51	4.0
6	13.9	0.40	532	0.4	65	3.0

Note: U_{phch} - quality of physical - chemical moisture.

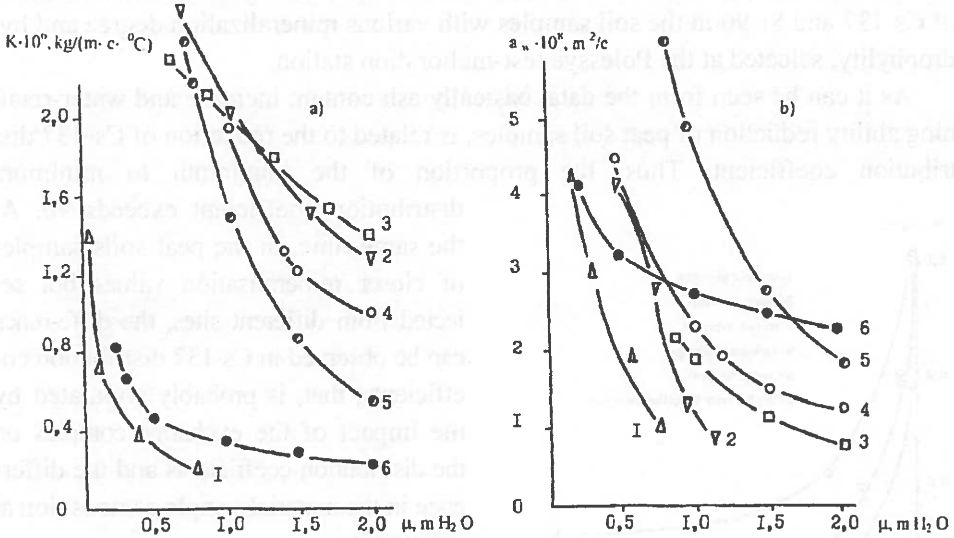

Fig. 6. Thermal-moisture conductivity indices (a) and diffusion (b) on moisture potential for peats and sapropel.

Efficient diffusion coefficients of Cs-137 and Sr-90 contrary to the distribution coefficients tend to become enhanced when the mineralization degree increases. Peat soils' moisture content also renders a direct impact upon the radionuclides diffusion mobility. While with the increase of mineralization degree, soil water-retaining capacity reduction occurs, the change of effective diffusion coefficient occurs to some lesser degree than corresponding distribution coefficient variation. This is obviously seen in a strongly mineralized sample 2, selected from the arable crop site cultivated since 1963. In the future studies on the assessment of degrading soils

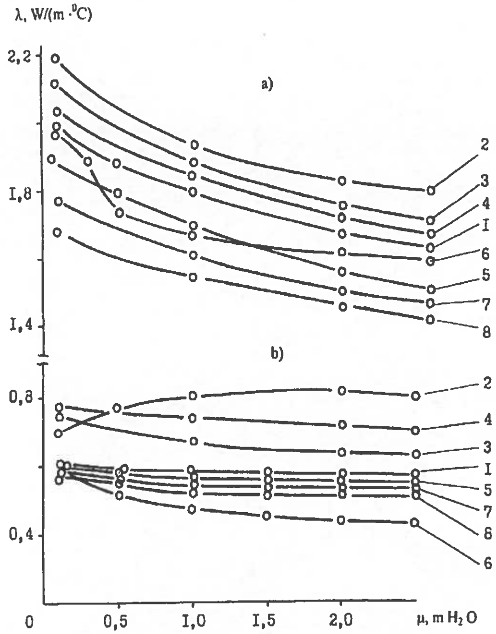

Fig. 7. Organogenic systems heat conductivity dependence index on moisture potential: a) in a frozen state; b) in a melted state; numbering of 1-6 curves corresponds to Fig. 5; 7 and 8-low - land

properties, one should pay attention to the change of kations of alkaline and alkaline-land metals correlation, as well as diffusion coefficients of these elements. It will make assessing of mobility of the mineral fertilizers applied possible and to reveal their application efficiency.

CONCLUSIONS

The complex of the equipment designed and methods worked out allow to investigate practically all the essential characteristics of the internal heat-mass soil transfer and to collect data for the mathematical modelling of interrelated processes of heat, moisture and water-soluable compound transfer in the active soil layer under daily and seasonal variation of heat-mass exchange conditions on their surface. Practical application of these studies should be directed to such issues, as forecasting extreme climatic phenomena in soils (droughts, light frosts) and taking up measures to reduce the scale of economic damage forecast and control processes of mineral fertilizer transfer that account for the dynamics of temperature and moisture regimes; development of methods radionuclide and heavy metal fixation or elimination from the root layer.

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Fig. 7. Dependence of soil heat conductivity dependence index on moisture potential: a) in a frozen state, b) in a melted state. Numbering of the curves corresponds to Fig. 5; 7 and 8 low - land

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