Thermophysical properties of lowland Histosols of the Upper Volga woodland (on the example of the Yakhroma river valley)

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Annotation. The dependence of thermal diffusivity on volumetric humidity for Histosols developed on wood peat, underlain by sediment peat and mineral peat, was studied using Histosols from the Yakhroma Valley (Moscow Region). The determination was carried out at the stages of drainage and humidification by the laboratory method of Kondratiev. For the stage of drainage, the dependence has a more pronounced dome-shaped form than for the stage of saturation. The highest values of thermal diffusivity were achieved with a volumetric soil water content of 50-55% for Histosols on wood peat and 40-45% for agromineral peat. The approximation of the data was carried out according to the equation of Chang and Horton. As a result of comparing the approximation parameters, it was revealed that they do not significantly differ from each other, which indicates the absence of hysteresis of the thermal diffusivity from humidity for the thermal diffusivity curve, the unambiguous values of which can be used to simulate the temperature regime.

1. Introduction
Climate change affects the course of intra-soil processes, soil functions in the biosphere. The impact of global climate change and local anthropogenic impacts has not been studied enough, both in Russian and in world science. In this regard, first of all, problems arise of the influence of temperature and humidity on soil productivity, their stability and carbon balance of peat soils, as the main intrazonal soils with a high content of organic matter. Given that Histosols are currently actively used in agriculture and determine the carbon balance in the surface layer of the biosphere, the temperature factor for biological activity is often limiting. There is little information to regulate and predict changes in the hydrothermal regime of Histosols, which are based on the dependence of soil thermal diffusivity on moisture. Histosol is distinguished by its specific physical properties: low density, hydrophobicity in the dry state, sharp swelling, so laboratory research is difficult [1-3]. This article presents the influence of the processes of desiccation and moistening on the dependence of the thermal diffusivity on moisture with an assessment of the possibility of a hysteresis of this dependence in these soils.

Under hysteresis in soil physics, we understand the change in the shape of the curve, depending on the direction or history of the process [4-5]. Most modern studies are aimed at identifying hysteresis for the water retention curve of mineral soils, while data on the presence or absence of hysteresis for the thermal diffusivity curve are currently practically absent. As known, one of the most likely causes of
hysteresis is a complex pore space. The structure of the pore space of peat is significantly different from mineral soils. Histosols and peat are a macroporous system. When filling its pores with water, significant swelling occurs, while at the same time, drying out can lead to a state of hydrophobicity. In this case, a "re-arrangement" of particles occurs, and the structure of the pore space changes. To regulate the temperature regime, it is necessary to know whether this affects the position of the curve of the dependence of thermal conductivity on volumetric humidity and whether this should be taken into account in the calculations.

The aim of the work is to study the dependence of thermal diffusivity on humidity at the stages of moistening (humidification) and drainage (desiccation), for the quantitative calculation and prediction of the hydrothermal regime of peat soils. Tasks: conduct laboratory studies of curves during wetting and drying for Histosols samples of the Yakhroma floodplain; approximate the data in the program Statistica; compare the obtained approximation parameters and identify if there are any significant differences between them.

2. Objects and methods
The object of the study is the lowland peat of the Dmitrov branch of the Federal Scientific Center “Soil Science Institute named after VV Dokuchaev”, located in the Yakhroma River Valley. Histosols developed on wood peat, underlain by a deposit of grass and sedge peat, located in the 8th quarter of Dalniy hospital and agromineral Histosols mosses from the 1st quarter of the Middle hospital were selected. Both hospitals are now in intensive agricultural use, “Middle” since 1914, “Far” from 1961-1965.

The selected wood peat is located in the central part of the floodplain, is well drained and less moisturized, consists of the remains of woody vegetation, and the remains of bog vegetation are also found [6,7]. These Histosols have a high degree of decomposition and high ash content (Table 1). Ash content is also affected by the continuous application of fertilizers. Groundwater is enriched in iron.

| Name of Histosols and underlying peat | Depth, cm | Decomposition degree, % | Ash content, % |
|-------------------------------------|-----------|-------------------------|----------------|
| Histosols developed on wood peat, underlain by grass sedge peat | 5 - 15 | 81.6 | 24.8 |
| | 25 - 40 | 69.5 | 20.1 |
| Agromineral Histosol | 5 - 15 | 79.8 | 23.2 |

As for agromineral peat, they are located in the near-river part of the valley and were formed during the floods of the river. Due to intensive agricultural activities, such as plowing slopes, peat formation stopped there and a layer of mineral sediment was deposited on top [6]. The layers of buried deluvium and alluvium have a great influence on the presence of minerals. They contain a higher content of potassium, phosphorus and magnesium compared to other peat layers [7].

In connection with the active use of these peat soils in agriculture, it is necessary to know their features of the thermal regime. This will allow you to choose more suitable crops, and the correct prediction of the temperature regime will increase yield. All this can be possible only in the case of a
detailed study of the dependence of the thermal diffusivity of peat on moisture and the preparation of forecast models [8].

The thermal diffusivity was determined by the laboratory method of Kondratiev [9, 10]. For the same sample, measurements were carried out at the stage of drying and moistening. The first curve was obtained by drying a pre-saturated peat column; upon wetting, the goal was to return to the original humidity. On the basis of the obtained data, two curves of the dependence of the thermal diffusivity on humidity were obtained, which, according to statistical processing, have no significant differences.

3. Results and Discussion

Figure 1 (a, b) shows the data of the dependence of thermal diffusivity on the moisture content of peat, developed on wood peat, underlain by a deposit of grass, sedge peat for layers 0-20 cm and 20-40 cm, obtained at the stage of drying and the stage of moistening. The graphs have the form of a dome-shaped dependence characteristic of mineral soils [10-12]. Naturally, with an increase in the volumetric moisture content, thermal diffusivity increases, reaching the highest value at a humidity of 50-55% in both cases. The highest values of thermal diffusivity in both cases are close to 4.16 cm²/h and 3.35 cm²/h for layers 0-20 and 20-40 cm, respectively. Reaching the maximum point, the values of thermal diffusivity begin to decrease. For graphs at the humidification stage, this is less pronounced. This type of dependence can be explained by an increase in the amount of water between the particles, and, accordingly, a decrease in the number of solid-phase contacts.

Figure 1 (c) shows similar curves obtained for agromineral peat. The graphs also have a domed character. The maximum value of thermal diffusivity is achieved at values of volumetric humidity of 40-45%, and after reaching the maximum thermal diffusivity begins to decrease. It should be noted that the highest values of thermal diffusivity are 4.9 cm²/h and 4.63 cm²/h at the stage of drying and moistening, respectively.

![Figure 1](image)

Figure 1. Dependence of thermal diffusivity (k, cm²/h) on volumetric soil water content (θ, %) for layers 0-20 cm (a) and 20-40 cm (b) of Histosols developed on wood peat, underlain by grass sedge peat and for a layer of 0-20 cm (c) agromineral Histosol.
Table 2 presents the main parameters of the approximation of the dependence of thermal diffusivity on humidity, obtained by nonlinear approximation. For the approximation, we used the polynomial model of Chang and Horton \( \kappa(\theta) = b_1 + b_2 + b_3 \times \theta^{0.5} \), where \( b_1, b_2 \) and \( b_3 \) are the approximation parameters that are used in mathematical modeling of heat transfer in soils [13-14].

It is important to note that the obtained parameters at a significance level of 0.05 are not significant. Probably, it is necessary to increase the number of repetitions and refine the methodology for determining thermal diffusivity by laboratory methods.

Table 2. Statistics of approximation parameters (\( b_1, b_2 \) and \( b_3 \)) of thermal diffusivity (\( \kappa, \text{cm}^2/\text{h} \)) versus volumetric humidity (\( \theta, \% \)) according to the equation \( \kappa(\theta) = b_1 + b_2 + b_3 \times \theta^{0.5} \) [15].

| Name of peat | Depth, cm | Process | Parameter | Value | Standard error |
|--------------|-----------|---------|-----------|-------|----------------|
| Histosols developed on wood peat, underlain by grass sedge peat | 0 - 20 | Drainage | \( b_1 \) | -9.957 | 9.591 |
| | | | \( b_2 \) | -0.262 | 0.232 |
| | | | \( b_3 \) | 3.774 | 3.005 |
| | | Humidification | \( b_1 \) | 0.197 | 10.907 |
| | | | \( b_2 \) | 0.0005 | 0.292 |
| | | | \( b_3 \) | 0.49 | 3.626 |
| Histosols developed on wood peat, underlain by grass sedge peat | 20 - 40 | Drainage | \( b_1 \) | 2.648 | 4.859 |
| | | | \( b_2 \) | 0.01 | 0.104 |
| | | | \( b_3 \) | 0.026 | 1.424 |
| | | Humidification | \( b_1 \) | -3.923 | 2.308 |
| | | | \( b_2 \) | 0.051 | 0.051 |
| | | | \( b_3 \) | 0.691 | 0.691 |
| Agromineral Histosol | 0-20 | Drainage | \( b_1 \) | -36.522 | 37.251 |
| | | | \( b_2 \) | -0.967 | 1.066 |
| | | | \( b_3 \) | 12.557 | 12.677 |
| | | Humidification | \( b_1 \) | -10.345 | 12.854 |
| | | | \( b_2 \) | -0.234 | 0.364 |
| | | | \( b_3 \) | 3.759 | 4.356 |

Knowing the approximation parameters, we can statistically compare the dependences of the temperature conductivity on humidity for the processes of drying and moisturizing, and we can conclude that they differ. We did this using the t-test, which is calculated by the formula [13]:

\[
t = \frac{|b_1 - b_2|}{\sqrt{(S_{b_1})^2 + (S_{b_2})^2}},
\]

where \( S_{b_1} \) and \( S_{b_2} \) — are the standard deviations of the parameters \( b_1 \) and \( b_2 \). Accordingly, if the t-criterion turns out to be more tabular for a given degree of freedom and significance level (traditionally 0.05), then the parameters of the two samples significantly differ from each other. In this case, it can be argued about the reliability of the differences in the corresponding characteristics of the process. In our case, the calculations showed that the curves do not differ significantly. This suggests that there is no hysteresis for the thermal diffusivity of peat soils and we may not take it into account in the calculations.
4. Conclusion
Histosols in their physical properties are very different from mineral ones. At the same time, they are actively used at the moment in agriculture, so the study of their properties is especially important. Temperature is often a limiting factor, and due to lack of data it is difficult to regulate. Due to the strong swelling and hydrophobicity of peat during desiccation, it is important to know that the dependence of thermal diffusivity on volumetric moisture, Histosols are characterized by an unambiguous dependence of thermal diffusivity on humidity, does not have hysteresis, and this dependence can be used to predict the thermal regime of soils both when they are moistened and when dried.

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