ГЕОЭКОЛОГИЯ

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EVALUATION OF THE INFLUENCE OF LARGE-SCALE MELIORATION OF THE BELARUSIAN POLESIE ON THE THERMAL REGIME OF SOILS

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Abstract

The article presents the results of modelling of heat distribution in the soil at different dehumidification standards. The method of mathematical modelling for obtaining the temperature profile of soils, which allowed to estimate the change of temperature and thermal regimes of the drained lands of Belarusian Polesie, has been proposed. The results obtained help to ensure optimal microclimatic conditions for the use of reclaimed land in agriculture.

Keywords: Belarusian Polesie, peat-bog soil, derm-podzolic soil, melioration, temperature, heat capacity, amount of heat

ОЦЕНКА ВЛИЯНИЯ КРУПНОМАСШТАБНОЙ МЕЛИОРАЦИИ БЕЛОРУССКОГО ПОЛЕСЬЯ НА ТЕПЛОВОЙ РЕЖИМ ПОЧВ

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Реферат

В статье приведены результаты моделирования распространения тепла в почве при различных нормах осушения. Предложена методика математического моделирования для получения температурного профиля почв, которая позволила дать оценку изменению температурного и теплового режимов осушенных земель Белорусского Полесья. Полученные в работе результаты способствуют обеспечению оптимальных микроклиматических условий для использования мелиорированных земель в сельском хозяйстве.

Ключевые слова: Белорусское Полесье, торфяно-болотная почва, дерново-подзолистая почва, мелиорация, температура, теплоёмкость, количество теплоты.

Introduction

The large-scale reclamation of Belarusian Polesie in the second half of the 20th century solved the problem of a complex of organizational-economic and technical measures to ensure the production of agricultural products by optimizing the water-air regime. As practice has shown, the reclamation in general has solved its tasks, but has had a significant impact on natural ecosystems, including the thermal regime of the territories.

The thermal regime, together with the water-air regime, mainly determine the agricultural productivity of the land. For this reason, the study of the laws of formation of the thermal regime of soils is one of the topical tasks of agriculture. Targeted management of this process will help to increase yields and improve the quality of cultivated crops.

Although the microclimate has a significant impact on crop growth and yield, insufficient attention is being paid to this factor. Fertilizer application, new varieties, weed control, etc. are generally considered. [1-3].

Belarusian Polesie is located within the Brest and Gomel regions, with an area of drained land of 7,315.9 and 1,415.5 thousand hectares respectively. This represents about 19% of all the lands of these regions [4], the main part of which is located on the territory of the Belarusian Polesie.

Agricultural expansion is not feasible in the short term, so intensification of crop yields is a priority. Of course, the main factor in its improvement, in addition to the quality of seeds and fertilizer application, is the amount of heat that falls on the soil surface, as well as the moisture supply of the root layer.

The nature of changes in the thermal regime of drained and uncultivated areas is different and is determined by both climatic factors and the degree of reclamation [5, 6]. In the first place, the coefficient of thermal conductivity varies from 0.1 W/(m⁰K) for dry peat to 0.5 W/(m⁰K) for humidified [7]. Due to better thermal conductivity, the lower layers of moist soil are warmer and hold the heat longer when the ambient temperature decreases.

Moist soil, due to the presence of water, has a higher heat capacity than drained, which contributes to the accumulation of more heat.

The main source of heat is the radiant energy of the sun. Absorbed by the soil, it is converted into heat, which is transmitted to the lower horizon or returned to the atmosphere, respectively, through the phenomena of thermal conductivity or thermal radiation and reflection [8]. The difference between the energy absorbed and the energy emitted is the energy that goes into heating the Earth's surface. As the temperature gradient between the upper and lower soil increases, more heat is spread to the lower layers [9].

Depending on the heat capacity, the soil accumulates a certain amount of heat. As the heat transfer process from the top to the bottom layers is rather slow, the excess energy will be further reflected into the atmosphere. As a result, the ground layer of air is heated more strongly, resulting in its movement to a lower pressure area. Thus, these air masses carry with them thermal energy from the drained territories [10].

The purpose of this study is to assess the change in the thermal regime of the reclaimed lands of Belarusian Polesie.

Research methods and baseline data

The study is based on the solution of the radiation balance equation, which forms the thermal regime of soils. The radiation balance is a variation of the law of energy conservation with its alterations and transformations to a specific area of soil. Figure 1 shows the heat exchange scheme between the earth and the environment [11].

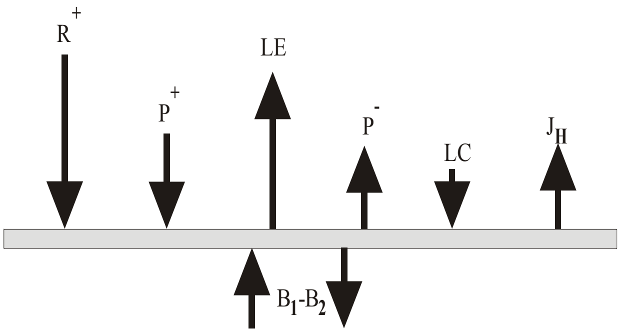

Figura 1 – Heat exchange scheme

The law of energy conservation in the heat exchange process occurs in accordance with the above scheme and is recorded as [11, 12]:

$$R^{+} + P^{+} + B_1 - B_2 = L \cdot E + P^{-} + J_{\text{H}} - L \cdot C, \qquad (1)$$

where R^{+} - radiation balance - the difference between absorbed short-wave (direct and scattered) radiation of the Sun and the balance of long-wave radiation (radiation of the Earth surface minus anti-radiation of the atmosphere) in the daytime and partly in the twilight hours of the day; P^{+} – positive component of turbulent heat exchange - heat that enters the land area due to air movement - adventive heat; B_1-B_2 – change of heat reserves in the active soil layer – heat exchange in the soil; LE – heat consumption for total evaporation; P^{-} – heat consumption for air heating - turbulent heat exchange; J_H - long-wave (effective) radiation of the earth surface in the night hours of day; LC – heat condensation; L – latent heat of water evaporation.

Equation (1) is greatly simplified if the following symbols are adopted:

– thermal power resources

$$L \cdot E_0 = R^{+} + P^{+} + B_1 - B_2, \qquad (2)$$

– total heat exchange

$$T = P^{-} + J_{\text{H}} - L \cdot C. \qquad (3)$$

Then it will appear:

$$L \cdot E_0 = L \cdot E + T. \qquad (4)$$

The E_0 value is equivalent to the heat energy resources of the heat exchange process (evaporation) and is expressed in the water layer thickness, which can evaporate when all heat resources are applied to the process. The T value is the total heat exchange for the heating of the ground air and for the night effective radiation of the Earth's surface, partially compensated by the anti-radiation of the atmosphere and the heat condensation of air vapors on the refrigerated elements of the Earth's surface [11, 12].

Water discharge during drainage directly or indirectly affects all components of the radiation balance. The exception is the annual average R^{+} radiation balance, which is stable for the area.

Thermal conductivity equation [13, 14, 15] was used to describe the regularities of soil temperature profile formation:

$$\rho C_p \frac{\partial T}{\partial t} = k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right), \qquad (5)$$

where ρ – density, kg/m3; C_p thermal capacity, J/(mol^{0}K); k – thermal conductivity, W/m^{0}K ; T – temperature, ^{0}K; ∇ – Hamiltonian.

Numerical modelling of the thermal regime of soils [16] is limited to calculation of the profile distribution of their temperatures [17]. The temperature at a given depth can be determined experimentally using modern thermal sensors [18, 19]. In practice, the use of these methods is difficult, as it requires a lot of equipment and measurements. At the same time, there are other methods for estimating soil heat at given depths, for example, through known soil surface temperature [20]. However, it is problematic to obtain a thermal conductivity function using the thermal wave method for large areas.

The solution to the above problem is mathematical modelling. To do this, it is necessary to determine the initial climatic conditions, which in turn will allow to calculate the temperature profile of the soil and to calculate the amount of heat accumulated by it.

In order to quantify the change in the heat intensity of soils, a numerical experiment has been carried out according to the following scheme: elementary volume of soils in 5 m^3 with dimensions of 1 m - width, 1 m - length and 5 m – depth; the chosen value of depth with reserve corresponds to the level, at which the temperature fluctuations associated with the degree of warming of the air by sunlight cease [21].

The study considered models of the two most common soils: peat-wetland, consisting of an upper layer of peat, 2 meters deep, and a lower layer of sand,3 meters deep; sodium-subtidal, which includes an upper layer of sand, 1 meter deep, and the bottom layer of coarse-grained sand, 4 meters deep. Since the largest area of the Belarusian Polesie occupies dernovo-subtidal soils (more than 35 %), then there are dernovo-subtidal wetlands (about 27.5 %) and peat-bog (about 20 %) [22].

For sod-subtidal soils, calculations were made at different groundwater levels (UHF): 0 m, 0.4 m, 0.8 m and 1 m.

The numerical solution of the mathematical model is obtained by finite element method [23].

On the basis of specialized software, a model of heat transfer in soil was created and its warming dynamics under natural conditions was investigated. [24].

The data were based on meteorological information on the Polesskaya meteorological station, which is located in the center of Belarusian Polesie and is representative for the region [25]. The air temperature was assumed to be the average multi-annual value for a given day at 19:00, which is the average temperature on the day in question.

Using the above method, a numerical experiment was performed to construct a temperature profile of soils for the following boundary conditions:

1. On the upper surface of the soil, the heat flux equals the average monthly solar radiation flow per unit area of the horizontal surface.
2. The condition of thermal stabilization at 9.1 ˚C [26] is set on the lower surface of the soil to the average annual temperature above the surface [27].
3. Convective heat exchange [12] was also specified on the soil surface:

$$\nabla(-k\nabla T) = 0. \qquad (6)$$

4. Thermal insulation conditions were applied on the lateral boundaries of the allocated volume.
5. Evaporation from the soil surface was defined as a change in the internal energy of the water during evaporation by the formula [28]:

$$Q = Lm - \nu RT, \qquad (7)$$

where L is the specific heat of vapor formation, J/kg; m is the mass of evaporated water, kg; v is the quantity of the substance of evaporated water, mole; T is the air temperature, ^{0}K; R is the molar gas constant, J/mol^{0}K.

Results and their discussion

As a result of the numerical experiment the soil temperature is distributed over the entire thickness of the simulated system with an averaging interval of 24 hours from May to October inclusive. As an example, figure 1 shows the dependency charts for the month of May.

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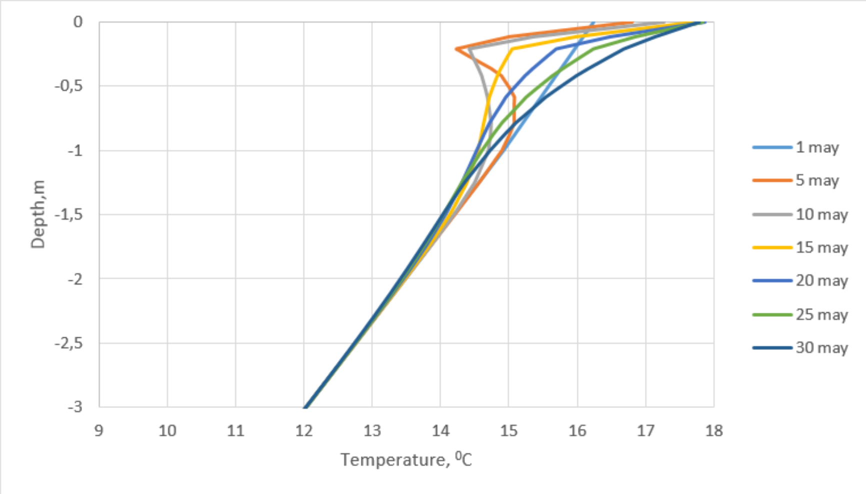

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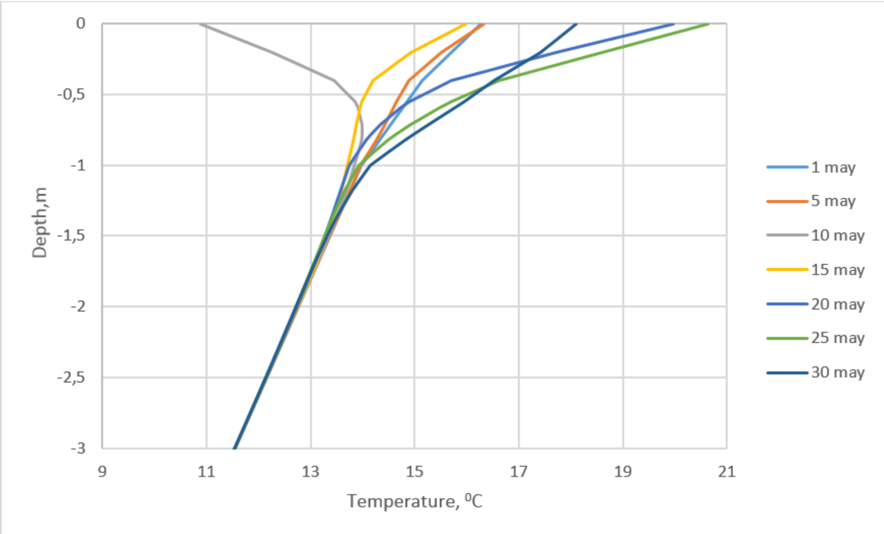
a)



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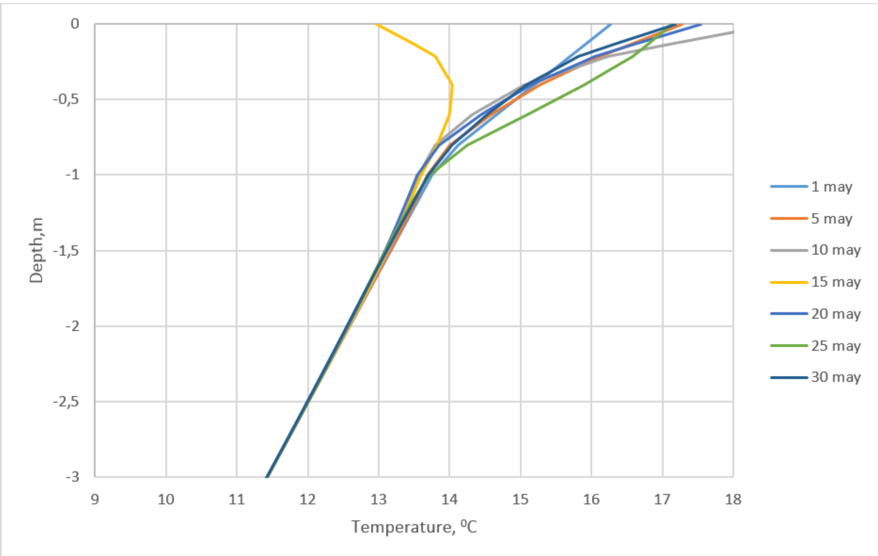
b)



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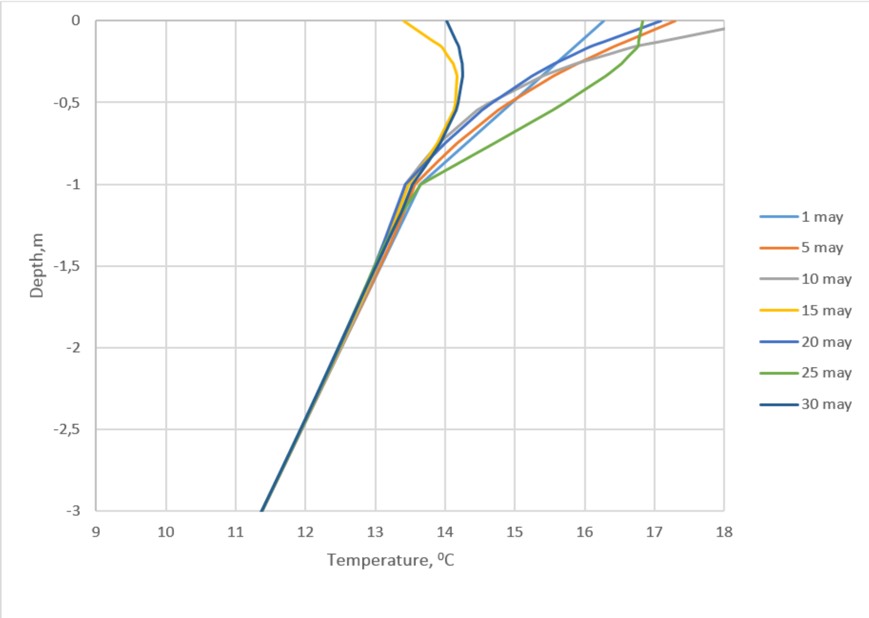
c)



d)

a) without drainage; b) with drainage at 0.4 m; c) with drainage at 0.8 m;
d) with drainage at 1 m

Figura 2 – Temperature distribution of sod-podzolic soil by depth for selected days

These graphs show that for drained land, the degree of dependence of soil heating in the surface layer is quite dependent on atmospheric temperature. For desiccated soils, the temperature variation over a month is 4˚C; for desiccated soils, the temperature is about 8˚C. This is due to the discharge of water from the root soil, which has a higher heat capacity than air.

On the graph for unspoiled soil, there are practically no temperature variations at a depth of about 1.5 m, and for drained soil this occurs at a depth of about 0.8 m. A similar picture is observed for the remaining months under consideration.

Consider the graphs in Fig. 3 showing the soil temperature distribution by depth for one day. The 1st of May was taken as an example. It follows that in the dried soil, when approaching the surface, the temperature grows at a higher rate than in the soil without drying. The temperature rise rate is seen to be at the upper level of the groundwater.

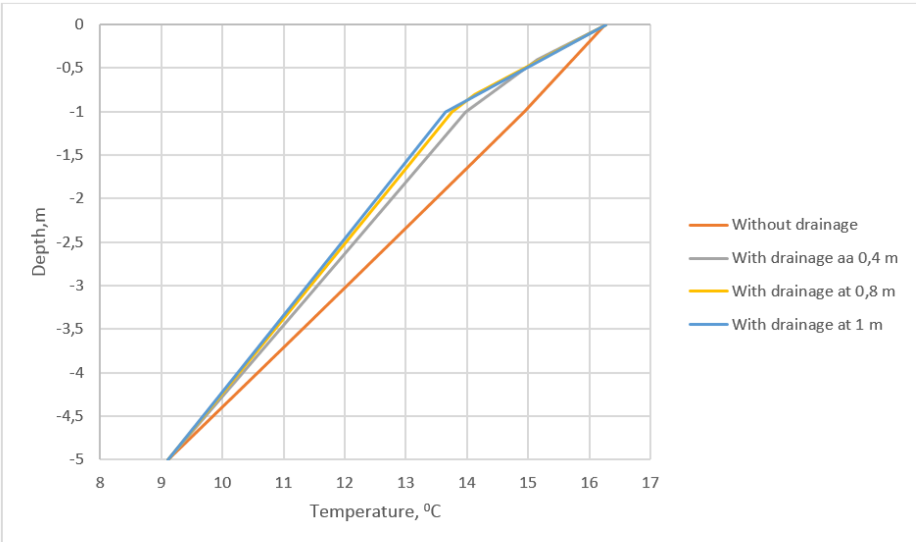


Figura 3 – Depth distribution of soil temperature for the 1st of May

For peat-bog soils, calculations were made for UGV levels of 0 m, 0.4 m and 0.8 m. Boundary conditions were chosen similar to those for dermis-subtidal soils.

As a result of the numerical experiment the temperature distribution over the entire thickness of the daily system under consideration was obtained from May to October.

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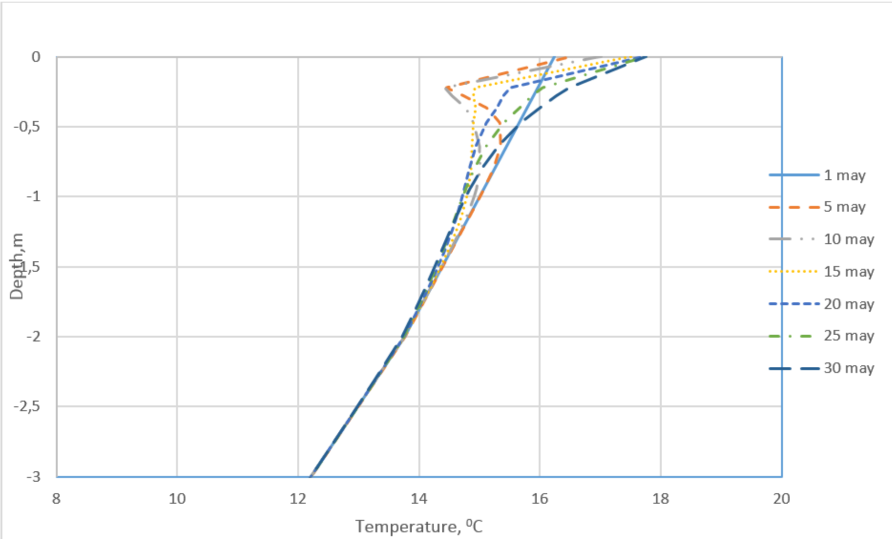
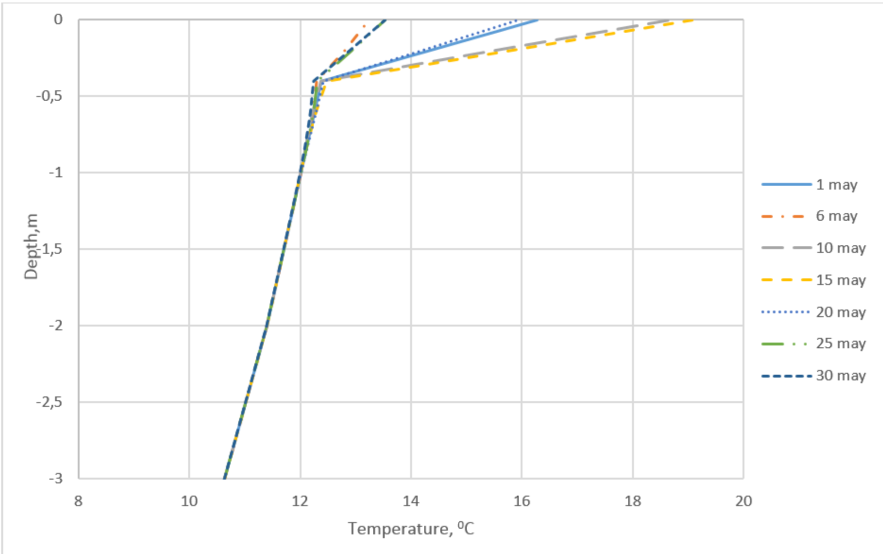


a)



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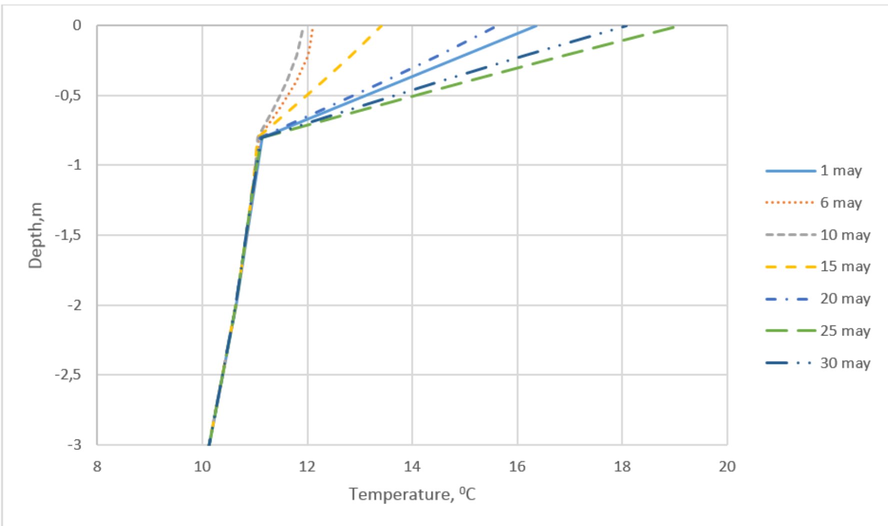


c)

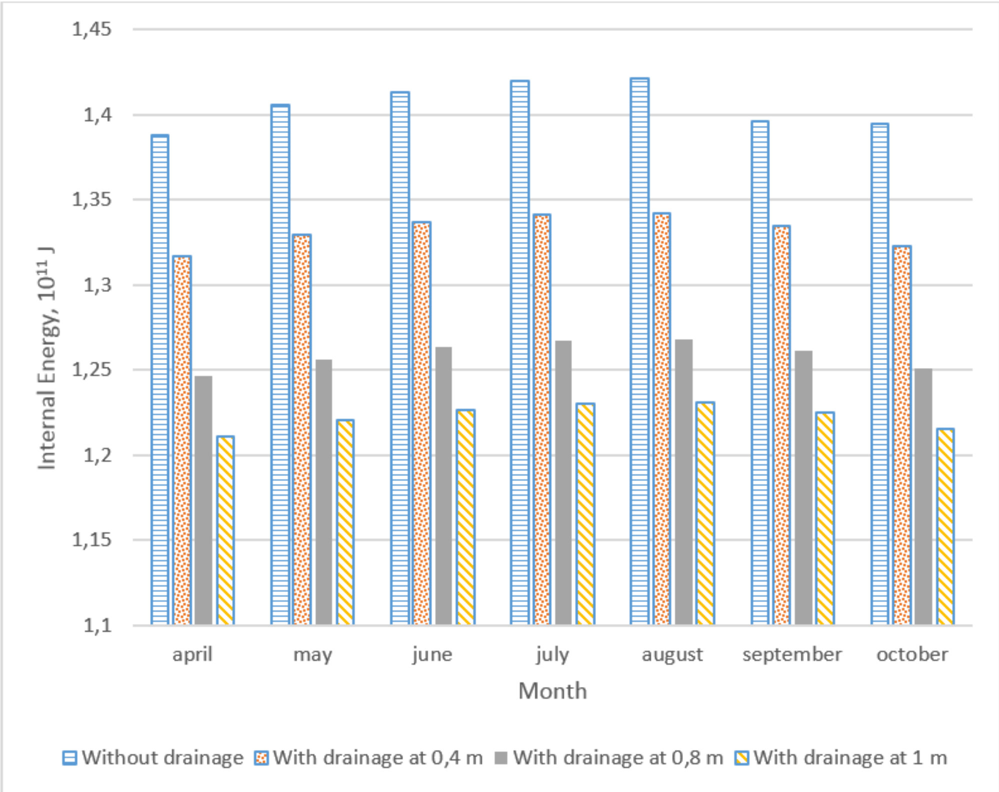
a) without drainage; b) with drainage at 0.4 m; c) with drainage at 0.8 m
Figura 4 – Temperature distribution of peat-marsh soil for selected days

Depending on soil properties at depths of 0.35 m to 1 m, daily fluctuations in soil temperature are attenuated [29]. So for the soil without drying, fluctuations of temperature values are practically not observed at a depth of about 1 m, and for the drained this happens already at a depth of about 0.8 m.

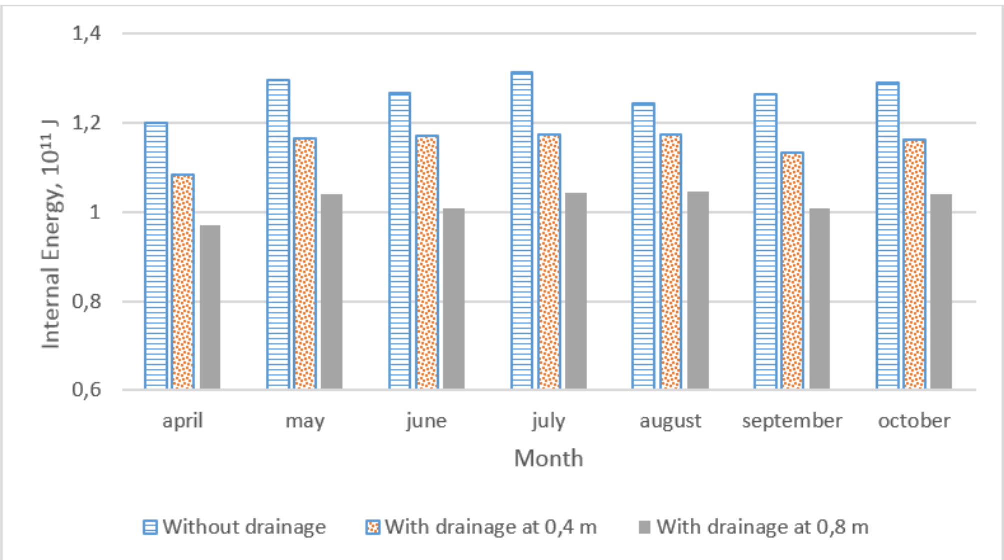
In the soil without drying, temperature variations begin to occur at a depth of approximately 2.5 m. As the surface approaches, the temperature rises evenly. At a depth of 2.5 m in the studied model lies a layer of constant temperature. But its jumps, which are observed on some days at a depth of about 0.2 m, are associated with the inertia of the process of heating the soil.

When the UGV is reduced by 0.8 m, ambient temperature variations have a significant influence on soil temperature already at the upper water level.

During the drainage process, as shown in the diagrams in Fig. 5, the amount of heat accumulated by the soil decreases with the decrease of the UGV. For dermal-subtidal soils, the energy difference before water discharge and with 0.8 m drainage reaches a maximum in August of 1.53 10^{10}J. For peat-wetlands, this value is the highest in July (2.7$10^{10}$J.), with the same dehumidification rate. In this way, dermal-sprinkled soils are more resistant to heat loss during drying.



a)



b)

a) Dermal-subtidal soils, b) Peat-wetlands

Figura 5 – Accumulated energy

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Thus, when draining the marshes together with water, a large amount of energy is taken, which is about 10^{10} J with 1 m^2 or 10^6 J per hectare. If we consider that the Belarusian Polesie, whose area is about 5 million hectares [9], is drained completely, the amount of heat that is missing the soil of the region during the growing season will be about 10^{16} J. For comparison: the installed capacity of the generation sources of the Republic of Belarus is 10 073.99 MW, which is 8.7 10^{14} J per day or 2.4 10^{12} J per year [30].

Conclusion

The reduction of the average heat capacity and thermal conductivity of the soil due to the reduction of its moisture content leads to a decrease in the amount of heat stored by the soil. This can lead to late frosts in spring and early autumn, which also do not contribute to increased crop yields. At the same time, the topsoil is re-dried and the growing conditions are unfavorable.

Therefore, when developing plans for the management of land reclamation systems, planning of crop rotation, selection of agrotechnical methods of cultivation of crops, it is necessary to take into account the processes of heat redistribution in the soil.

References

1. Zhuravlyov, M. Z. Plodorodie nizinnyh bolot podtayozhnoj zony Irtysh-Ishimskogo mezhdurech'ya i nekotorye voprosy ih sel'skohozyajstvennogo ispol'zovaniya / M. Z. Zhuravlyov // Nauch. tr. OmSKHI. – Omsk, 1963. – T. 1. – S. 61– 70.
2. Motorin, A. S. Plodorodie torfyanyh pochv Zapadnoj Sibiri / A. S. Motorin // Melioraciya i vodnoe hozyajstvo. – 2020. – № 1. – S. 16–22.
3. Kurchevskij, S. M. Sravnitel'naya ocenka peskovaniya i glinovaniya dlya povysheniya produktivnosti torfyanyh pochv / S. M. Kurchevskij, E. I. Podnebesnaya // Agrohimicheskij vestnik. – 2013. – № 2. – S. 27–28.
4. Gosudarstvennyj zemel'nyj kadastr Respubliki Belarus' (po sostoyaniyu na 1 yanvarya 2021 g.) Komitet po zemel'nym resursam, geodeziya i kartografiya. – Minsk, 2021.
5. Mazhajskij, Yu. A. Povyshenie produktivnosti melkozalezhnyh torfyanyh pochv pri vnesenii mineral'nyh dobavok / Yu. A. Mazhajskij, S. M. Kurchevskij // Agrohimicheskij vestnik. – 2015. – № 1. – S. 15–17.
6. Iglovikov, A. V. Fiziko-himicheskie svojstva i pitatel'nyj rezhim narushennyh gruntov Krajnego Severa pri biologicheskoj rekul'tivacii / A. V. Iglovikov, A. S. Motorin // Agrarnyj vestnik Urala. – 2012. – № 7 (99). – S. 66–72.
7. Dobrynin, V. M. Petrofizika (Fizika gornyh porod): Ucheb. dlya vuzov. 2-oe izd. pererab. i dop. pod red. D. A. Kozhevnikova. – M. : FGUP Izd-vo «Neft' i gaz» RGU nefti i gaza im. I. M. Gubkina, 2004. – 368 s.
8. Kormilicina, O. V. Pochvovedenie / O. V. Kormilicina [i dr.]; pod obshch. red. V. A. Rozhkova. – M. : Izd-ij dom «Lesnaya promyshlennost'», 2006. – 272 s.
9. Prirodoobustrojstvo Poles'ya: monografiya: v 4 kn. / pod obshch. nauch. red. Yu. A. Mazhajskogo [i dr.]. Brest; Rovno; Varshava; Ryazan': Meshcherskij filial VNIIGiM im. A. N. Kostyakova, – 2019. – Kn. 1 : Belorusskoe Poles'e. – T. 2 : Preobrazovanie i ispol'zovanie prirodnyh resursov. – 503 s.
10. Habutdinov, Yu. G. Uchenie ob atmosfere: uchebnoe posobie / Yu. G. Habutdinov, K. M. Shantalinskij, A. A. Nikolaev. – Kazan' : gos. un-t, 2010. – 257 s.
11. Volchek, A. A. Gidravlika, gidrologiya, gidrometriya: uchebnoe posobie / pod obshch. red. A. A. Volcheka, P. V. Shvedovskogo, N. N. Sheshko. – M. , Izd-vo Knorus, 2021. – 520 s.
12. Gidrologicheskie raschyoty v meliorativnyh celyah: uchebnoe posobie / V. S. Mezencev [i dr.]. – Omsk : Omskij SKHI, 1980. – CH. 1. – 81 s.
13. Tihonov, A. N. Uravneniya matematicheskoj fiziki / A. N. Tihonov., A. A. Samarskij. – M. : Izd-vo MGU, 1999. – 799 s.
14. Modeli produkcionnogo processa sel'skohozyajstvennyh kul'tur / R. A. Poluektov [i dr.]. – SPb. : Izd-vo S-Peterb. un-ta, 2006. – 799 s.
15. Hvorova, L. A. Dinamicheskoe modelirovanie i prognozirovanie v agrometeorologii / L. A. Hvorova, A. G. Topazh – Barnaul : Izd-vo Altajskogo gos. un-ta, 2010. – 262 s.
16. Shein, E. V. Kurs fiziki pochv / E. V. Shein. – M. : Izd-vo MGU, 2005. – 432 s.
17. Hvorova, L. A. Chislennoe modelirovanie sostavlyayushchih teplovogo rezhima pochv Altajskogo Priob'ya / L. A. Hvorova, A. V. Zharikov // Zhurnal Izvestiya AGU. – 2013. – № 1. – T. 1. – S. 126–130.
18. Bolotov, A. G. Izmerenie temperatury pochvy s pomoshch'yu tekhnologii 1-Wire / A. G. Bolotov // Vest. Altajskogo gos. agrarnogo un-ta., – 2012. – № 11. – S. 29–30.
19. CS230 Temperature Profiler. Revision: 4 /17: instruction manual // Campbell Scientific [Elektronnyj resurs]. – Rezhim dostupa: https: www.cs230.pdf – Data dostupa: 14.02.2022.
20. Opredelenie profil'nogo raspredeleniya temperatury pochvy na osnovanii temperatury ee poverhnosti / E. V. SHein [i dr.] // Zhurnal Zemledelie. – 2018. – № 7. – S. 26–29.
21. Volchek, A. A. Ocenka vliyaniya osusheniya na teplovoj rezhim pochv Poles'ya / V. V. Borushko, A. A. Volchek // Kompleksnye problemy tekhnosfernoj bezopasnosti. Nauchnyj i prakticheskij podhody k razvitiyu i realizacii tekhnologij bezopasnosti : sb. tezisov po materialam XVII Mezhdun. nauch.-prakt. konf. – Voronezh, 2021. – S. 57–58.
22. Prirodoobustrojstvo Poles'ya : monografiya : v 4 kn. / pod obshch. nauch. red. YU. A. Mazhajskogo, A. N. Rokochinskogo, A. A. Volcheka, O. P. Meshika, E. Eznaha. – Ryazan' : Meshcher. f-l FGBNU «VNIIGiM im. A. N. Kostyakova», 2018. – Kn. 1 : Belorusskoe Poles'e. – T. 1 : Prirodno-resursnyj potencial. – 408 s.
23. Dul'nev, G. N. Primenenie EVM dlya resheniya zadach teploobmena / G. N. Dul'nev, V. G. Parfenov, A. V. Sigalov. – M. : Vysshaya shkola, 1990. – 208 s.
24. Borushko, V. V. K voprosu o vliyanii osusheniya na teplovoj rezhim meliorirovannyh zemel' Belorusskogo Poles'ya / V. V. Borushko, A. A. Volchek, V. I. Gladkovskij // Aktual'nye problemy nauk o zemle: ispol'zovanie prirodnyh resursov i sohranenie okruzhayushchej sredy : sb. materialov mezhdun. nauch.-prakt. konf., posvyashchyonnoj Godu nauki v Respublike Belarus' 25 – 27 sentyabrya : v 2 ch. / BrGU imeni A. S. Pushkina. – Brest, 2017. – CH. 2. – S. 6–9.
25. Borushko, V. V. Ocenka vliyaniya osusheniya na teplovoj rezhim pochv Poles'ya / V. V. Borushko, A. A. Volchek // Kompleksnye problemy tekhnosfernoj bezopasnosti. Nauchnyj i prakticheskij podhody k razvitiyu i realizacii tekhnologij bezopasnosti : sbornik statej po materialam XVII Mezhdun. nauch.-prakt. konf. – Voronezh, 2021. – S. 368–374.
26. WeatherOnline Ltd. – Meteorological Services [Elektronnyj resurs]. – Rezhim dostupa: Temperature – Brest – Climate Robot Belarus (weatheronline.co.uk). – Data dostupa: 10.10.2022.
27. Regional'naya fizicheskaya geografiya. Klimaty Zemli: ucheb.-metod. posobie: V 2 ch. / E. M. Zubashchenko [i dr.]. – Voronezh : VGPU, 2007. – CH. 1. – 183 s.
28. Mihajlyuk, Yu. I. Orientirovochnaya osnova dejstvij pri izuchenii himii elementov v kurse obshchej himii: uchebnoe posobie / YU. I Mihajlyuk, A. K. Mazitova, R. R. Kudoyarova. – Ufa : Izd-vo UGNTU, 2004. – 197 s.
29. Pochvovedenie s osnovami geologii: uchebn. Posobie / A. I. Gorbylyova [i dr.]. – Mn. : Novoe znanie, 2002. – 480 s.

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