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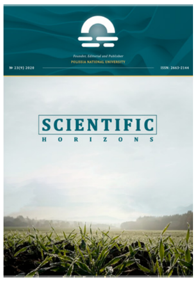


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## Influence of Climate Changes on Hydrothermal Regime of Dark Gray Podzolized Soil of Western Forest Steppe


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**Abstract**. Thermal properties of soil are important conditions that determine the nature and intensity of soil processes, but the features of the formation of thermal and water regimes of dark gray podzolized soil of the Ukrainian Forest Steppe are insufficiently studied. The purpose of the presented materials is to highlight the dynamics of the annual course of temperature and humidity of the air and dark gray podzolized soil to determine the peculiarities of the formation of its hydrothermal regime in modern agro-climatic conditions of the Forest Steppe zone. The study of soil temperature was carried out during 2008-2019 in the Rivne region using generally accepted standards and methods (DSTU ISO 11464-2007, DSTU ISO 11465-2001, DSTU B B.2.1-17:2009, DSTU B B.2.1-25:2009). Surface air temperature observations throughout the study period indicate an increase in average annual temperature, and five-year averages of the sum of effective air temperatures above 10°C show tends to increase. The study of the relationship between the temperature of the surface air layer and dark gray soil in the Rivne region confirmed that the correlation of these indicators is linear. Analyzing the dynamics of temperature indicators, it should be noted a significant increase in maximum soil temperatures, due to which there is an increase in average annual temperatures. Detailing of soil warming indicators according to the data of ten years showed that during 2008-2017 the soils warmed up much more than in the average during the whole period of meteorological observations. According to the accepted classification, the studied soils belong to the seasonally freezing type, moderately warm subtype and genus with medium heat supply. The results obtained during the study allow to justify changes in the hydrothermal conditions of dark gray podzolized soil and determine the needs for corrective measures in crop production to maintain sustainable yields and ensure enhanced fertility reproduction



**Keywords**: global warming, air temperature, soil temperature, soil warming index, sum of temperatures, moisture supply, $CO_2$ emissions



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## INRODUCTION

Soil temperature and its thermal properties are important conditions that determine the nature and intensity of soil processes, including synthesis, destruction of substances, biodynamic of soil [1; 2]. C.A. Aliev noted that the increase in soil temperature leads to the accelerated of rock decay, increases the intensity of chemical and biological processes occurring in the soil cover [3]. Later this was the development of work of O.H. Chuian and L.N. Karaulova, which emphasized the determining influence of general climatic conditions of the territory on formation of physical and chemical properties of zonal soils and their oxidation-recovery, living and other modes [4].

Since the beginning of the XXI century, much of the attention of scientists is directed at studying the manifestations of so-called "global warming" or global climate change. In this context, research of hydrothermal regime of soils has gained new relevance and new faces, in particular – a separate section has become the study of processes of transformation of organic substance and associated emission of greenhouse gases [5]. According to this, in studying the role of the temperature factor in the soil processes it is possible to allocate a classical period, under which the general regularities of the course of soil processes were substantiated depending on temperature conditions and degree of soil moisture [6-8] and the modern period, the main tasks of which were the study of the extent and speed of changes in the general agro-climatic conditions of territories [9], as well as the reaction of field crops to these changes. The latter aspect was studied in a rather deep way in the world scientific community, so Carlos Garcia described in detail not only the important role of soil in the carbon cycle, but also its reaction to the change of $CO_2$ in the atmosphere [10], similar conclusions follow from R. Chauhan [11] and D. Uprety in their work [12] noted the importance of taking into account the actual agro-climatic parameters of the territory when planning technological approaches to field crops cultivation, as the latter are sharply reacting to climate changes.

A significant number of researches are carried out concerning formation of temperature regime of soils of the boreal forest with limited thermal resources, in which dried peat [13-15] and mulch podzolized soils [16-18] are researched. The above articles are informative for understanding of the orientation of the ground processes and general regularities of the soil reaction on climatic changes, but not presented for the forest-steppe soils. So N. Koronatova in her work [15] highlighted the modern hydrothermal regime of boggy soil, and S. Veremeenko based on general methodological approaches to soil management of Polesia under different conditions of their thermal supply. Preliminary studies have found that the soils are sufficiently dynamic to react to the increase of warming, and thus changes not only the speed of the biochemical processes, but also, in some cases, their direction [17].

Some works focus on the study of the black soil area [4], but they can also be applied to the forest-steppe zone only partially because of significant differences in the structure and composition of soils, in particular – in times smaller content of organic substances. Thus, at the present stage of the law-making and peculiarities of the formation of thermal, water regimes of the dark-gray podzolized soil of the forest-steppe of Ukraine are not studied enough. The issues of changing elements of their hydrothermal regime in the context of climate change, which have been evident over the past 10-15 years, are particularly urgent.

*The purpose of the study* was to study dynamics of the annual course of temperature and humidity of air and dark gray podzolized light loamy soil to determine the peculiarities of formation of its hydrothermal regime. The expected result is the determination of actual parameters of heat and moisture supply of the territory, which was investigated as the basis for planning further measures on rational use of available soil resources.

## MATERIALS AND METHODS

The study of temperature conditions of dark-gray podzolized soil in 2008-2019 was carried out on the territory of Rivne region (Western Forest Steppe of Ukraine) on the research field of the Department of agricultural chemistry, soil science and arable farming of the National University of Water Economy and Nature Management. Location of the site: 50°35'59.9"N 26°19'33.1"E. Before placing the experimental site, three main soil sections and a number of brackets were laid for the determination of general genetic peculiarities of the soil and its local differences. According to the results of the research it was found that the available soil type is dark gray podzolized light loamy, zonal for the Western forest-steppe of Ukraine. The content of humus 1.4-1.45%, the power of humus-eluvial horizon up to 30 cm, the reaction of soil solution is subacid.

All field observations on the research site were performed in accordance with the current standards and methods of agrometeorological and soil observations (DSTU ISO 11464-2007 [19], DSTU ISO 11465-2001 [20]) and in accordance with [21]. In the warm season the soil temperature was measured with the help of mercury thermometers, which were installed at the depth 5, 10, 20, 30, 40, 50, 80, 100 cm, measuring accuracy 0.1°C. For monitoring of temperature on small (5, 10, 20 cm) depths were used the Savinov elbow thermometer, for other depth – soil thermometers. During the winter period the observations lasted until the beginning of soil freezing, in some years it was possible to carry out twelve-month studies.

Soil moisture was determined by a thermostatic-weight method every decade; samples were taken in the field for the eighth day of the decade after 10 cm to the meter depth (DSTU B. 2.1-17:2009 [22]). Drying of selected samples was carried out to a constant mass at a temperature of 105 degrees. After 6 hours of drying, the cooling in the desiccator and the first weighing was performed, after which the drying time was repeated for 1.5 hours. In case of significant differences between the indicators, carried out further drying for an hour.

The precipitation was measured with the help of the field pluviometer M-99 at a height of 250 cm above the ground level, accounting was carried out with accuracy up to 1 mm. The depth of seasonal freezing and defrosting – the field cryopedometer (DSTU B.V. 2.1-25:2009 [23]). Since during the past 15 years the temperatures of the winter period in some years of soil freezing were not significantly increased. Laboratory researches were carried out on the basis of department of agricultural chemistry, soil studies and arable farming with the use of certified and tested in the established order equipment. The site where the accounting devices were laid is open, flat. Plant of grass, natural for forest-steppe zone.

Also, as source materials were used logs of archive data of multi-year meteorological observations of Rivne Regional Center of Hydrometeorology. The partial data are present for the period from 1945, the full list of indicators is available for the period from 1987. The data digitization for the further statistical processing full rows of observation data were used, without the use of a sample. Statistical processing of data obtained from field and laboratory observations was carried out with the use of commonly accepted methods, with the help of Microsoft Excel, Statgraphics Centurion, Statistica.

## RESULTS AND DISCUSSION

### *Atmospherical temperature and rainfall amount*

According to the Ukrainian Hydrometeorological Center of climatic norms, the average annual air temperature in the Rivne region should be 7.0°C, the temperature amplitude is small, typical for a moderate continental climate. The average temperature of the coldest month (January) is set at -5.4°C, July – 17.8°C. The transition through zero mark and fast warm air begins in the middle of March, from September there is a cooling, reverse transition to sub-zero temperature in November. However, according to the observations on the temperature of the ground air layer during the entire investigated period for 1945-2019, the growth of the average annual temperature is noted (Fig. 1).

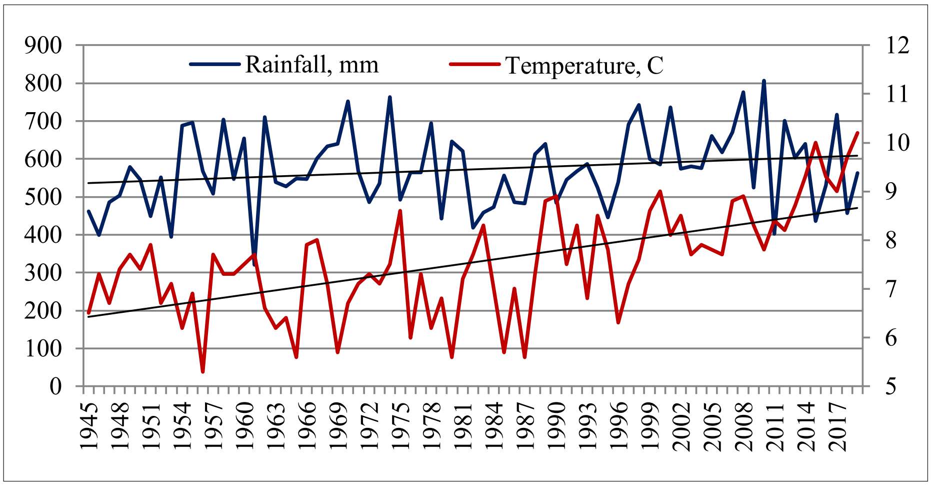


***Figure 1****. Average annual temperature of air (T) and amount of rainfall (R) on the meteorological station of Rivne (according to the Rivne Center of Hydrometeorology)*

The trend growth of the indicator for the period 1986-2019 is about 1.8°C and is formed mainly due to the warm period of the year (period of effective temperatures).

At the same time, the sharp rise in temperatures after 2005, which was also noted by other authors [24]. However, the figures are much higher than the average on the planet, and according to the National Oceanic and Atmospheric Research Administration of the United States (NOAA), the region to which Ukraine belongs, has one of the highest rates of temperature growth in the world, which is approximately 3.5 times higher than in the average on the planet [25].

The five-year average shows that effective temperatures above 10°C vary in the range of 800-1200 degrees. At the same time, throughout the period the trend toward the increase of this indicator is clearly highlighted (Fig. 2). Most of the annual amount is formed during June-August. The maximum number of effective temperatures is recorded annually in July; an excess increase is formed mainly during July-August. In 2012, the record value of 1428°C was reached, subsequently exceeded 1500°C and continues to grow. With the increase in the threshold, the percentage increase in annual amounts increases, so if the sum of temperatures is higher than 5°C recently than the average multi-year figure by 16%, the same amounts above 10, 15°C exceed the average values by 23 and 39% respectively. This indicates that the rise in the average temperature of the warm air, which was discussed above, is due to the rise in high temperatures in the warmest months (July-August). The duration of the warm season in autumn is also increased.

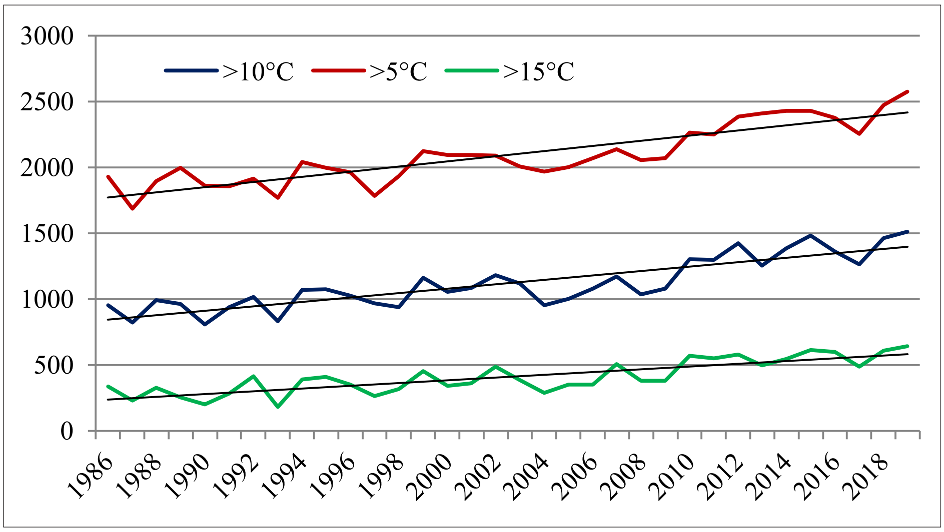


***Figure 2**. Sum of effective temperatures, 1986-2019*

Analysis of the number of precipitations according to the observations, during 1945-2019 shows a significant variation in both the number and distribution of precipitations during the year. On average, for the whole period of observation there were 577 mm of precipitation per year, but during the year their distribution did not always correspond to the standard dynamics. In the winter and spring months of precipitation was less normal, in the summer-autumn period there was a reversal trend. The annual rainfall dynamics has been growing (Fig. 1). To similar conclusions came in their researches M. Barabash and O. Tatarchuk [26]. In this case, from the point of view of influence on the soil cover of increase of heat supply has a more significant influence, than a mineral growth of precipitations. Moreover, preliminary studies of the effect of warming on evaporation of moisture from soil [9] have shown that the increase in soil moisture loss can occur at a higher rate in relation to the increase in humidity as a result of rising precipitation.

### *Moisture and soil temperature*

The above mentioned regularity is confirmed by the deposits of moisture data during the warm period in layer 0-20 and 0-50 cm. In the spring there will be a clear increase in the deposits of moisture in both explored soil horizons (Fig. 3).

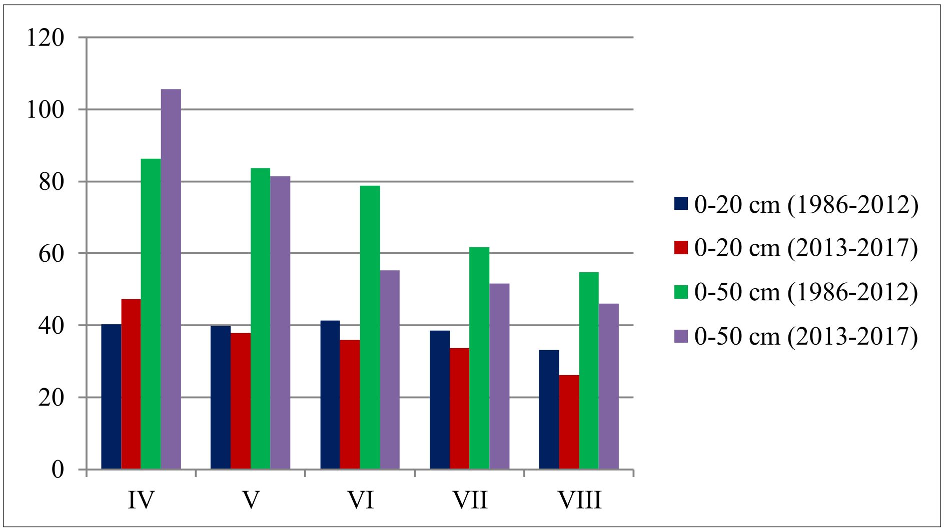


***Figure 3**. Comparison of deposits of moisture in layers 0-20 and 0-50 cm for periods 1986-2012 and 2013-2017, mm*

Despite the higher deposits of moisture at the beginning of vegetation, in May the average amount of available moisture is less than the many years' norm, which can be explained by more intensive water evaporation due to better heat supply. During the summer period, the trend is only increasing. The data received generally correlate with data received in other regions [24; 26]. Thus, the trend toward changes in the general agroclimatic conditions is similar for the regions of the country, but their intensity is very varied. Based on the average data, the graph of availability of dark gray soil by moisture is presented in Figure 4.

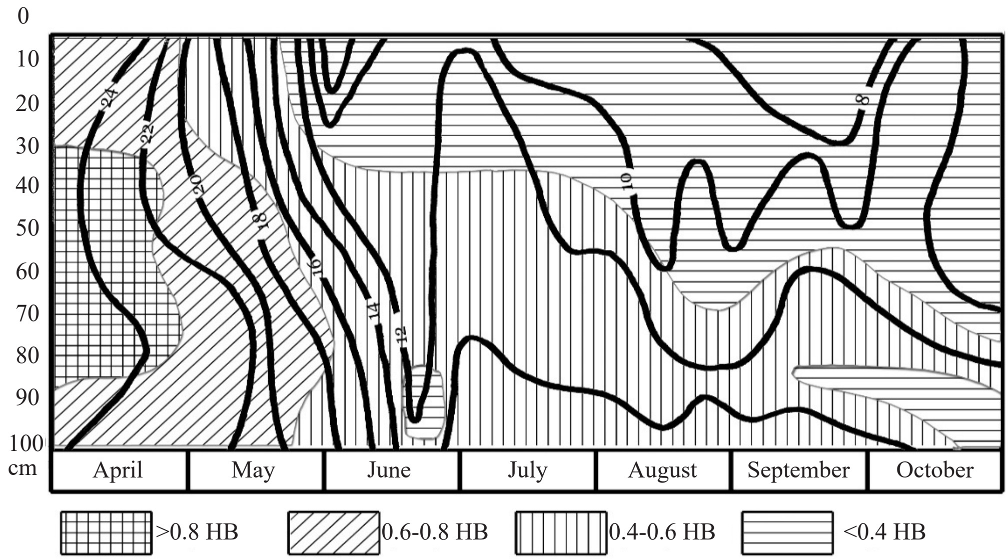


***Figure 4**. Water availability of dark gray podzolized soil, averaged data*

Monitoring of air temperature and precipitation during 2008-2019 showed that the average annual temperature during all years significantly exceeded the long-term norm, while the main increase was formed due to the warm period of the year (May-September). The study of dependence between the temperature of the ground air layer and dark gray soil in conditions of Rivne region confirmed that correlation of these indicators is linear.

The annual cycle of soil temperature completely repeats the cycle of air temperature. The rise in soil temperature is observed in March, reaching the maximum in July month, in August begins to cool down the top soil, annual minimum in late January – the first half of February. In order to determine the general trends of the long-term course of the dark gray soil temperature, processing of the database of the Rivne Center of Hydrometeorology for 1986-2019 was carried out the data of decades' temperature of dark gray soil on the depths of 5, 10, 15 and 20 cm. The average increase in the temperature of the top soil during the warm period is 2.1°C, which is much more than the similar indicator for the air temperature. This regularity confirms that the rise in surface soil temperatures occurs at a much higher rate relative to the established rates of so-called global warming, the determining benchmark for which is the temperature of the surface air.

The analysis of the annual cycle of soil temperature showed that the temperature is above +10°C in the top soil in the second-third decade of April. The isotherme of 10°C falls annually below 100 cm already in early May. Temperature +15°C at a depth of 20 cm comes in the second decade. In the years with delays in heat in the spring, the soil can be heated for 10-15 days later. In May, hot surfaces continue and heat migration is intensified down the soil profile, at a depth of 50 cm reach temperatures above 15°C, at a meter depth – up to 13°C. June is marked by the continued warming of deep soils and stabilization of surface horizon temperatures at 20-22°C. July is considered the warmest month, on the surface of temperature can pass a threshold of 30°C, on the depth of the horizon fixed average monthly temperature of 22.8°C, the soil is warmed up to 20 degrees below 50 cm, to 17.7°C at a depth of 100 cm. In August, heat is extended to the depth, while the surface layers begin to cool. The reverse transition through a 10°C threshold in the top soil occurs in mid-October, deeper effective temperatures are stored until the end of the month. During the active heating, the temperature difference in the depths of 5 and 20 cm is 3.5-4.0°C, in the summer period 2.0-3.0°C, and gradually decreases with the beginning of cooling. The oscillation of temperature maximums at that is shown even more strongly than on the surface. The delay of spring heating in comparison with the surface is 18-20 days, as against 5 cm depth – 12-15 days. The ground is heated above 10°C from May to October. The depth of penetration of temperatures above 15°C is from 100 to 150 cm and more depending on the conditions of the year. The temperature of the top soil in the summer does not exceed 22...24°C. Isopleth +18°C, reaches the maximum mark of 90...100 cm in early August, +20°C – in July passes at a depth of 30 cm. Thus, during the vegetation period in the soil profile prevail temperatures of 10...22°C. Temperatures above 22°C can be observed only in the layer 0...10 cm. The cooling takes place in September-October, the temperature in the top soil quickly decreases and in the second decade of October falls below +10°C, and by the middle of November does not exceed 3...4°C. The cooling dynamic follows the dynamics of the surface horizon with a slight delay. The annual temperature stroke at a depth of 50 cm has a number of features. Spring heating is more generalized and less dependent on short-term weather conditions of a given year, but penetration of high amplitude allows to better detect years with atypical strong spring and summer heating (2010, 2012), and the suspension of temperature maximums is well shown tendency to delay autumn cooling. The dynamics of the annual temperature circle at a depth of 100 cm is illustrated by the delay in heat at a depth, at a time when the surface layers actively give it. The years with early spring heating (2008) are clearly shown, the trend is better to extend the period of active temperatures in autumn. The long period of research shows that vegetation is stopped in the first-second decade of November. During the monitoring period, there is a noticeable tendency to decrease the depth of freezing, so if according to the average data of the hydrometeorological center in 1985-1989 the maximum depth was 68.2 cm, the average – 39 cm, then over the last five years these indicators have fallen to 18.4 and 8 cm respectively (Fig. 5).

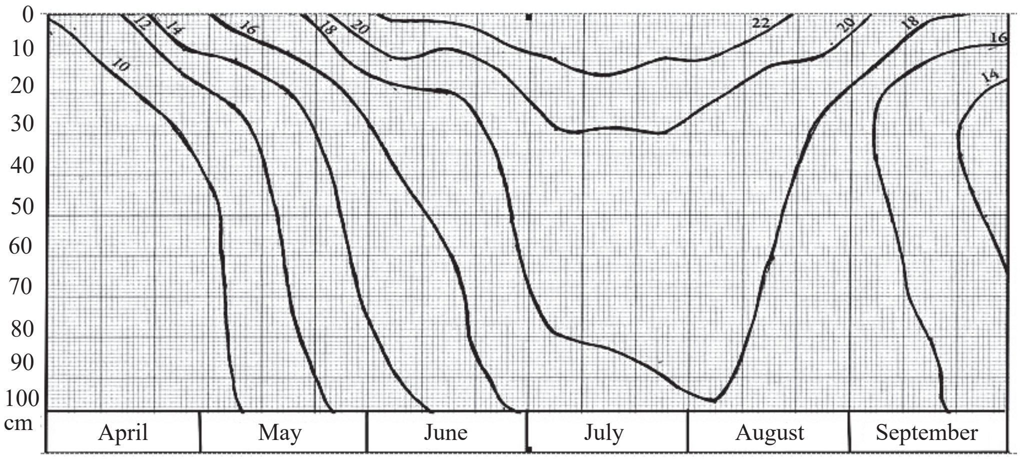


***Figure 5**. Thermoisoplethes of dark gray podzolized soil, averaged data*

The general circle of soil temperature is fully in line with the classical substantiation [6], but the presence of a number of obvious differences, which is probably the result of the development of climate changes of the XXI century. In particular, the absolute values of temperatures in the soil profile are increased, the penetration depth of thermal insulation is greater, the period of maintenance of high temperatures in the top soil and at the depth is prolonged, which creates conditions for prolongation of vegetation period of winter crops in autumn, and possibly requires correction of the terms of their dropping. Such a tendency with high probability can be scaled on adjacent agro-climatic zones, taking into account the same direction of the climatic factors [24; 27].

### *Changes in soil heating*

Analyzing the dynamics of temperature indicators, it is necessary to note a significant increase in temperature maximums, due to which growth of average values of annual temperatures is observed. Soil heating is an integral process, which depends not only on global factors, but also on many factors and conditions of local character – meso- and micro-relief, nature of the underlaying layer, type and method of soil use, etc. That is why the soil warming index, proposed V. Dimo [6], is an important indicator in the assessment of the heat supply of soils. It represents the ratio of the sum of effective soil temperatures above 10 degrees at a depth of 20 cm to the equivalent sum of effective air temperatures. The details of this indicator according to ten years showed that during 2008-2017 the soils were heated much more strongly than in the average for the whole period of meteorological observations (Table 1).

***Table 1**. Calculation of soil warming index*

| Year | The sum of effective soil temperatures>10°C at a depth of 20 cm, °C | The sum of effective air temperatures >10°C, °C | Soil warming index | The sum of effective soil temperatures >15°C at a depth of 20 cm, °C | The sum of effective air temperatures >15°C, °C | Soil warming index |
|---|---|---|---|---|---|---|
| 2008 | 2993 | 2656 | 1.13 | 2377 | 1868 | 1.27 |
| 2009 | 2780 | 2735 | 1.02 | 2231 | 1978 | 1.13 |
| 2010 | 3322 | 2804 | 1.18 | 3107 | 1771 | 1.75 |
| 2011 | 3193 | 2718 | 1.17 | 2845 | 2254 | 1.26 |
| 2012 | 3859 | 3128 | 1.23 | 3635 | 2179 | 1.67 |
| 2013 | 3387 | 2890 | 1.17 | 2964 | 2063 | 1.43 |
| 2014 | 3754 | 3074 | 1.22 | 3369 | 2276 | 1.48 |
| 2015 | 3865 | 2995 | 1.29 | 3487 | 2468 | 1.41 |
| 2016 | 3491 | 2896 | 1.20 | 3006 | 2312 | 1.30 |
| 2017 | 3652 | 3167 | 1.15 | 3291 | 2443 | 1.35 |
| Average | 3429.6 | 2906.3 | 1.176 | 3031.2 | 2161.2 | 1.405 |

First of all, it should be noted that the value of the indicator of the soil warming index during all years above the unit, that is, even at the depth of the top soil of the investigated soil is characterized by higher temperatures than air. The absolute values of the soil warming index vary from 1.02 to 1.29, reaching the maximum values in 2012 and 2015. At the same time, if you compare the dynamics of the index with the dynamics of the initial parameters, it is easy to notice that the soil warming index reproduces the dynamics of the course of the soil temperatures, while the air temperature does not make a serious impact.

The results of statistical analysis showed that the total correlation between the soil warming index and the initial parameters is 99.21% at standard and absolute accuracy, respectively, 0.0179 and 0.019. The regression equation of the water absorbing capacity dependence on the initial parameters (1) can be defined as:

$$Soil\ warming\ index = 1.14932 + 0.000776816 \times \text{Тп} - 0.000901762 \times \text{Тв} \quad (1)$$

where Тп and Тв are the sum of soil temperatures more than 10°C (at a depth of 20 cm) and air.

Similar to its nature is also the indicator of soil warming index proposed by S.I. Veremeenko [15]. It represents the ratio of soil temperatures to air temperatures, but the threshold value is higher and is 15°C, which allows to estimate the change in the temperature regime of the soil in the area of high temperatures. This is especially relevant in conditions of sharp increase of summer temperature maximums. During 2008-2017, the Veremeenko index ranged from 1.13 to 1.75. Note that the maximum values were observed in 2012 and 2010 and were caused by abnormally strong warming of the soil cover, while the sum of air temperatures were close to the norm. In 2010, the amount of soil temperature for the first time recorded is higher than 3000°C, the year was considered extremely hot. However, already in 2012 the indicator exceeded 3500°C, at high, but far not record, the sum of air temperatures 2179 degrees (Table 1). It is worth noting that relative deviations of the sum of effective soil temperatures (-21.4 ... +28,0%) is much higher than similar fluctuations of air temperatures (-11.9...+12.1%). In addition, if you compare the variation of the sum of temperatures above 10 and above 15°C, then immediately noticeable increase of fluctuations with the increase of the threshold value. This regularity clearly indicates that the existing changes in the temperature regime of dark gray soil are particularly acute in a period of high temperatures, which can significantly affect the growth of many traditional crops, especially against a background of lack of precipitations in the same period.

In recent years, average decades' air temperatures have exceeded 30°C, and in some days were fixed temperatures above 35°C. And if at a depth of 20 cm the soil, according to the calculations, is heated by 50-87% stronger, then on the surface of temperature could reach critical for the development of plants, causing drought, accelerated mineral erosion of organic substance, evaporation and general soil degradation. According to the proposed S.I. Veremeenko (1997) classification, investigated soils belong to seasonal-intermediate type, moderately warm sub-type and type with average heat supply (annual amount of soil temperatures within 2400-3000°C), but change of agro-climatic conditions of the territory was reflected on their taxonomic position. According to the archive data of the first jumps in the amount of annual soil temperatures to the area with good heat supply observed in 1995 and in the period 1999-2002, and since 2005 a complete transition has taken place. A significant deviation can be considered only 2009 years, when the sum of temperatures was 2780 degrees. At that 3859°C in 2012 get already in zone of sufficient heat supply (Fig. 6).

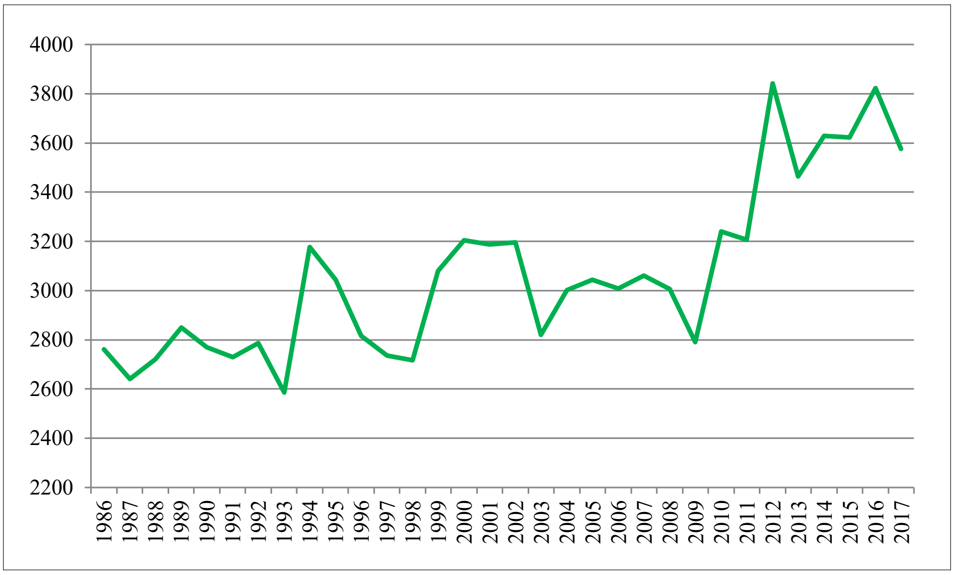


***Figure 6***. *Change of the annual sum of soil temperatures above 10°C*

In subsequent years, the sum of temperatures is stable in the zone of sufficient heat supply, the average for the period of 2013-2017 indicator is 3629.8 degrees. From the point of view of the typification of hydrothermal regime for S.I. Veremeyenko [9], a classic dark gray podzolized soil belongs to the optimal group with medium heat supply against the background of periodically flushing regime.

## CONCLUSIONS

Climatic changes in the territory of the Western forest-steppe led to increase of air temperatures throughout the year, and during the warm period in particular. At the same time, annual amounts of effective air temperatures above +5, +10 and +15°C. A characteristic increase in relative temperature rise with a threshold increase from +5 to +15 degrees. The changes have also affected the moisture regime, in particular, the annual amount of precipitations has a slight increase, which in other equal conditions would lead to better maintenance of moisture. However, it is necessary to take into account the parallel increase in heat supply of the territory, which inevitably leads to an increase in evaporation of moisture. At the same time, the uneven distribution of precipitation has increased significantly during the year – long periods of heavy rainfall and periods of heavy rainfall have appeared, which creates additional risks for agriculture.

The observations made by the authors also showed that despite the growth of spring deposits of moisture, in the summer period soil often moves to critical values and in general there is a tendency to decrease the supply of plants by moisture at this time, which is critical for growing. In the complex with the above mentioned changes of heat supply there is a potential danger of shift of hydrothermal regime of investigated soil from group optimal in group satisfactory, with sufficient supply of thermal resources and insufficient moisture supply and, as a result, strengthening processes of transformation of mineral part and organic substance of soil.

It was found that on the territory, which was researched, changes in the main climate-forming indicators – average annual air temperature, sum of effective air temperatures, amount of precipitations are actively shown. In addition to quantitative changes, changes in heat and moisture distribution are also shown throughout the year. In the complex this led to changes in the soil thermal maintenance – increase of the available heat resource, increase of maximum temperature values, decrease of freezing depth and height of snow cover, and, as a result, – change of classification position of the territory according to the indicator of hydrothermal regime.

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## Вплив кліматичних змін на гідротермічний режим темно-сірого опідзоленого ґрунту Західного Лісостепу

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**Анотація**. Теплові властивості ґрунту є важливими умовами, що визначають характер і інтенсивність ґрунтових процесів, однак закономірності та особливості формування теплового, водного режимів темно-сірого опідзоленого ґрунту Лісостепу України вивчені недостатньо. Метою представлених матеріалів є висвітлення динаміки річного ходу температури і вологості повітря та темно-сірого опідзоленого легкосуглинкового ґрунту для визначення особливостей формування його гідротермічного режиму в сучасних агрокліматичних умовах зони Лісостепу. Вивчення температурного режиму ґрунту проводилося протягом 2008–2019 рр. на території Рівненської області із використанням загальноприйнятих стандартів і методик (ДСТУ ISO 11464-2007, ДСТУ ISO 11465-2001, ДСТУ Б В.2.1-17:2009, ДСТУ Б В.2.1-25:2009). Дані спостережень за температурою приземного шару повітря протягом усього досліджуваного періоду вказують на зростання середньої річної температури, також усереднені по п'ятиріччям дані показують, що суми ефективних температур повітря вище 10°C мають тенденцію до збільшення. Аналіз кількості опадів протягом 1945–2019 рр. вказує, що багаторічна динаміка річної суми опадів має зростаючий тренд. Дослідження залежності між температурою приземного шару повітря і темно-сірого ґрунту в умовах Рівненської області підтвердило, що кореляція цих показників має лінійний характер. Аналізуючи динаміку температурних показників, слід зазначити істотне підвищення максимальних температур ґрунту, за рахунок яких і спостерігається зростання середніх значень річних температур. Деталізація показників прогрівання ґрунту за даними десяти років показала, що протягом 2008–2017 рр. ґрунти прогрівалися значно сильніше, ніж у середньому за весь період метеорологічних спостережень. Згідно із прийнятою класифікацією досліджувані ґрунти належать до сезоннопромерзаючого типу, помірно теплого підтипу і роду з середнім тепло забезпеченням. Отримані при виконанні дослідження результати дозволяють обґрунтувати зміни гідротермічних умов темно-сірого опідзоленого ґрунту та визначити необхідність запровадження коригуючи засобів у рослинництві для підтримання сталих врожаїв і забезпечення розширеного відтворення родючості

**Ключові слова**: глобальне потепління, температура повітря, температура ґрунту, індекс прогрівання грунтів, сума температур, волого забезпечення, емісія $CO_2$