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УСОВЕРШЕНСТВОВАНИЕ ГТК СЕЛЯНИНОВА ДЛЯ РАСШИРЕНИЯ ВОЗМОЖНОСТЕЙ ЕГО ПРИМЕНЕНИЯ

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Приведены основные моменты, определившие необходимость и сущность разработки комплексного гидротермического коэффициента (ГТКк). Данную разработку следует рассматривать как процесс усовершенствования гидротермического коэффициента Г.Т. Селянинова. Предложенный ГТКк позволяет более детально характеризовать территорию. Комплексный ГТКк включает в себя две составляющие: тангенсальную ГТК*t* и радиальную ГТК*r*. При графическом отображении ГТКк рационально выделять зоны, соответствующие ГТК*t*, внутри которых формировать зоны, соответствующие ГТК*r*. Приведено распределение ГТКк в Новосибирской области. Величина интервала тангенсальной зоны выбрана постоянной и составляет 0,2 мм/град. Величина радиальной зоны несколько варьируется для исключения мелких образований на границах зон. Приведенная карта-схема агроландшафтного районирования Новосибирской области позволяет сопоставить ее с распределением ГТКк. Определенное их сходство подчеркивает соответствие комплексного ГТКк тем природным процессам, которые определяют развитие растений. Дан пример применения ГТКк при его отображении на мелкомасштабной карте. Показано, что при перемещении в выбранной полосе карты Российской Федерации с севера на юг среднее значение радиальной составляющей последовательно изменяется от 70,5 до 155. Это соответствует изменению условий для произрастания растительности, в то время как предшествующий ГТК находится в одном и том же интервале. Переход к комплексному ГТКк также предоставляет возможность оценить распространение тех или иных растений на новых территориях при возрастающем потеплении. Исходя из положений модели, определяющих развитие растений в зависимости от погодных условий, возможно выделить набор параметров конкретного растения. Данные параметры соответствуют оптимальным значениям температуры и осадков на определенных фенологических фазах растения, а также определяют соответствующие им показатели климата, по близости данных наборов оценивают уровень благоприятности распространения растения.

Ключевые слова: климат, гидротермический коэффициент, осадки, температура, модель

IMPROVEMENT OF THE SELYANINOV HTC TO EXPAND THE POSSIBILITIES OF ITS APPLICATION

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The main points that determined the necessity and essence of the development of the complex hydrothermal coefficient (HTCc) are given. This method should be considered as a process of improving the hydrothermal coefficient of Selyaninov G.T. The proposed HTCc allows for a more detailed characterization of the territory. The complex HTCc includes two components: the tangential HTC*t* and the radial HTC*r*. In the graphical representation of HTCc, it is rational to allocate zones corresponding to HTC*t* within which to form zones corresponding to HTC*r*. The distribution of HTCc in the Novosibirsk region is given. The value of the tangential zone interval is chosen constant and is 0.2 mm/degree. The size of the radial zone varies slightly to exclude small formations at the boundaries of the zones. The given map-scheme of agro-landscape zoning of the Novosibirsk region allows to compare it with the distribution of HTCc. A certain similarity between them emphasizes the correspondence of the complex HTCc to those natural processes that determine the development of plants. An example of the application of HTCc when it is displayed on a small-scale map is given. It is shown that when moving in a selected zone of the map of the Russian Federation from north to south the average value of the radial component consistently changes from 70.5 to 155. This corresponds to a change in the conditions for vegetation growth, while the preceding HTC is in the same interval. The transition to a complex HTCc also provides an opportunity to assess the distribution of certain plants on new territories with increasing warming. Based on the provisions of the model determining the development of plants depending on weather conditions, it is possible to identify a set of parameters of a particular plant. These parameters correspond to the optimum values of temperature and precipitation at certain phenological phases of the plant and determine their corresponding climate indicators, and by the proximity of these sets assess the level of favorability of the spread of the plant.

Keywords: climate, hydrothermal coefficient, precipitation, temperature, model

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INTRODUCTION

In market conditions the purpose of any enterprise is to increase the efficiency of its activities, and the way of increasing - intensification. However, as follows from the work [1], regardless of the level of intensity of agricultural technologies used, there is an increase in the cost of obtaining an additional unit of agricultural production. The data given by FAO on the world grain production shows that both the decline and the rise in this process are determined by climatic conditions. Scientists believe that in the next decade the growth of production in agriculture on the basis of scientific and technological progress will occur due to the improvement of ways to obtain and effectively use information about the climate[1]. It is believed [2-5] that the territorial organization of natural-agrarian systems largely depends on the solution of problems of efficient and ecological use of land for agricultural purposes. In this connection, higher and higher requirements are imposed on the characteristics and indicators determining the state of territories [6, 7]. The implementation of the topical issue of improving the known and developing new models of the basic agricultural processes also stimulates the above trend [8, 9].

Of the existing indicators used to assess agroclimatic resources, the most widely used is the hydrothermal coefficient (HTC) of G.T. Selyaninov, calculated by the formula

$$\text{HTC} = \Sigma p \cdot 10/\Sigma t,$$

where Σp is the sum of precipitation for the period with average daily air temperatures above

[1]Climate and Agriculture: [Electronic resource] - http://collectedpapers.com.ua/ru/climate_and_human_activities/klimat-ta-silske-gospodarstvo (accessed: 14.01.2021).

10 ºC, Σ*t* is the sum of active temperatures accumulated during the same period.

In 1928, G.T. Selyaninov proposed the term "climatic factors of crops", which over time was transformed into "agro-climatic indicators". One of such indicators - the hydrothermal coefficient (HTC) - entered the practice of the world science getting his name.

Despite its widespread use, HTC has certain disadvantages. The main drawback is that for areas with low temperatures and humidity (the Arkhangelsk Region, the Komi Republic), as well as for areas with high temperatures and precipitation (the Black Sea coast of the Transcaucasian Region), HTC has approximately equal value, although agroclimatic conditions in these areas are incomparable[2]. There is a need to supplement HTC with a component of amplitude nature (for example, such as $z = f1(p) + f2(t)$, where *p* is precipitation; *t* is temperature).

The purpose of the research is to develop a promising agro-technical indicator to assess the state of the territories, ensuring the achievement of practically significant results in agricultural production.

RESULTS AND DISCUSSION

To elaborate the issue of eliminating the shortcomings of HTC and expanding its possibilities of practical application, let us consider the mapping of temperature (*t*) and precipitation (*p*) factors on a graphical plane in which temperature (*t*) is represented by abscissa. Let the point A_i with coordinates p_i and t_i be a characteristic of climatic (or weather) conditions of a particular small area. In this case, the ratio P_i / t_i is the tangent of the angle α′ formed by the abscissa and the line extending from the origin to point A_i. Nothing will basically change if the variable $\sum t$ is plotted along the abscissa axis and $\sum p$ along the ordinate, which are characteristic of the chosen time interval ΔT. Then the similar point A_j, being a characteristic of the climatic conditions in the time interval ΔT, is uniquely defined by the coordinates $S'p_j$ and St_j:

$$S'p_j = \sum_{i = k_j}^{l_j} p_i,$$

where p_i is the measured value of precipitation with the number *i*; *j* is the number of interval ΔT; k_j is the number of measurement corresponding to the starting point of the *j*-th interval; lj is the number of measurement corresponding to the end point of the *j*-th interval:

$$St_j = \sum_{i = k_j}^{l_j} t_i$$

where t_i is the measured temperature value with number *i*; *j* is the number of interval ΔT; k_j is the number of measurement corresponding to the starting point of the *j*-th interval; l_j is the number of measurement corresponding to the end point of the *j*-th interval.

The ratio $10 \cdot S'p_j/St_j$ corresponds to the Selyaninov HTC and simultaneously, as noted above, is the tangent of the angle α.

Next, it is advisable to switch to the polar coordinate system. In this coordinate system, the point Aj noted above is described by the angle α′ (uniquely defined by tgα′) and a radius equal to $\sqrt{(S'p_j)^2 + (St_j)^2}$.

Thus, the climatic characteristic of the chosen territory is rationally presented in the complex variant (complex hydrothermal coefficient - HTCc), represented by two components: tangential ($10 \cdot S'p_j / St_j$) and radial ($\sqrt{(10 \cdot S'p_j)^2 + (St_j)^2}$). It should be noted that the complex hydrothermal coefficient can be equally represented by two variants: the first in the form of tangential and radial components and the second in the form of angular and radial components. However, taking into account G.T. Selyaninov's huge contribution, his intuition and ability to identify indicators of undoubted practical value, it is proposed to use the variant with tangential and radial components as the main variant in the future, and to pass to application of the following expressions:

$$Sp_j = 10 \cdot S'p_j;$$

$$\text{HTC}t = Sp_j/St_j;$$

$$\text{HTC}r = \sqrt{(Sp_j)^2 + (St_j)^2}.$$

[2]Konstantinov A.R. Weather, soil and yield of winter wheat. L.: Gidrometeoizdat, 1978. 248 p.

Although the variant with tangential and radial components is the most acceptable for most cases, this does not exclude the use of the second variant, if necessary.

The schematic map of the Novosibirsk region is shown in Fig. 1 to demonstrate the capabilities of the proposed HTCc. On this schematic map, the zones to which a given interval of the tangential component of the HTCc corresponds are highlighted. Most of the above mentioned zones are subdivided into small zones, which correspond to the radial components of the HTCC. The zones are designated by a two-digit code, in which the first digit determines the number of the tangential component, and the second digit corresponds to the radial component of HTCc. If there is only one radial zone within a particular tangential zone, then in Figure 1 the zone number is indicated by one digit corresponding to the number of the tangential zone, and a two-digit code is added in brackets next to this number in the text. Thus, in Fig. 1, the zones that do not have a small (radial) zone split are identified. Proceeding from the prevalence of knowledge on Selyaninov's HTC among specialists of this subject, it was decided to apply the same units for quantitative characterization of the tangential component of the HTCc as for Selyaninov's HTC.

The value of the tangential zone interval is chosen constant and is 0.2 mm/degree. The value of the radial zone varies slightly. This is caused by the desire to reflect the change in the radial component inside the tangential zone and to exclude small formations at the boundaries of the zones, arising due to the possible inter-

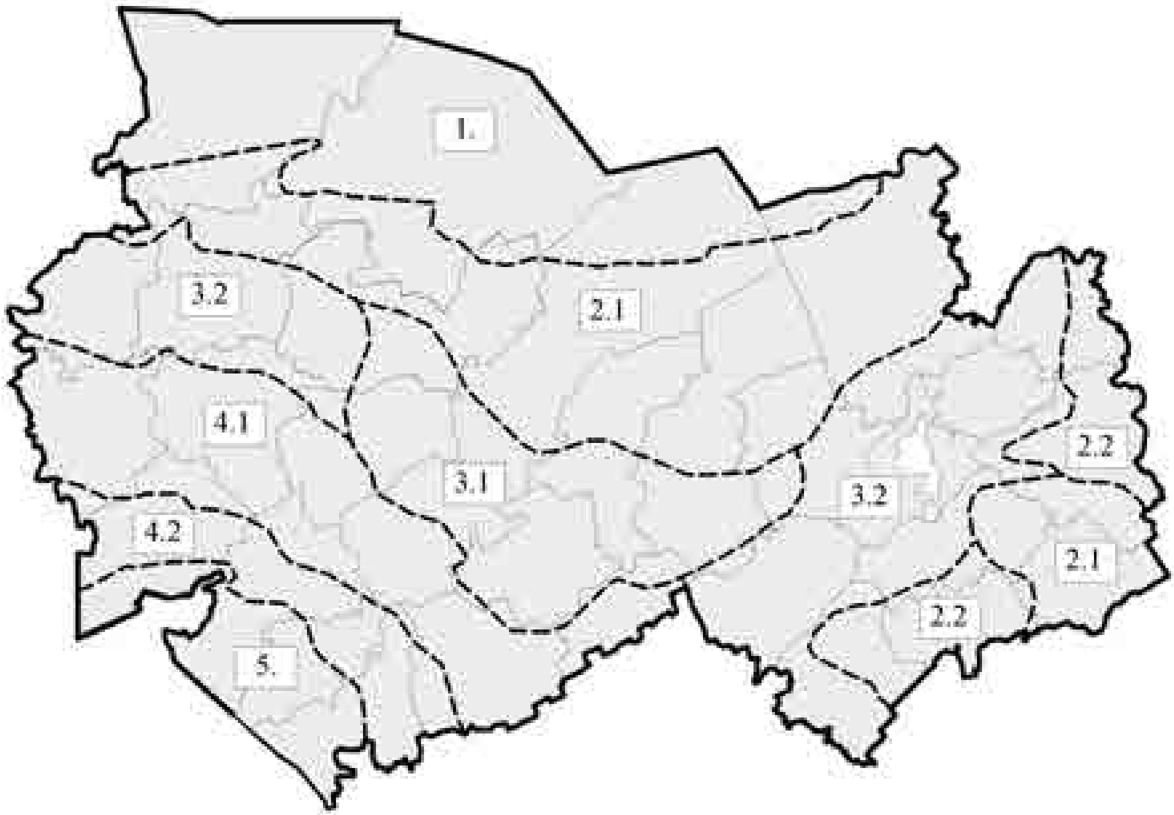

Рис. 1. Распределение ГТКк в Новосибирской области:

1.; 5. – номера зон, не имеющих дробления зонами другого вида; 1.1; 1.2; …; 4.1; 4.2. – комплексные номера зон, где первая цифра соответствует номеру зоны с тангенсальной составляющей, вторая – номеру зоны с радиальной составляющей

Fig. 1. Distribution of HTCc in the Novosibirsk Region:

1.; 5. - numbers of zones that have no fragmentation by zones of another type; 1.1; 1.2; ...; 4.1; 4.2. - complex zone numbers, where the first number corresponds to the number of the zone with tangential component, the second number corresponds to the number of the zone with radial component section of the constant zones. The specific magnitudes of the zones are given in the table.

Figure 2 shows the agrolandscape zoning map of the Novosibirsk Region [10]. It is the result of long-term research by researchers at the Siberian Research Institute of Soil Management and Chemicalization of Agriculture of the Siberian Branch of the Russian Academy of Agricultural Sciences, which made it possible to include the results in the materials on the formation of adaptive-landscape farming systems.

Comparison of the two given schematic maps allows us to note their certain similarity in spite of the fact that they differ significantly in the data used for their development. This circumstance emphasizes the correspondence of the complex HTCc to those natural processes that determine the development of plants. Moreover, there is a high probability that the farming systems proposed by the first and second schematic maps will be almost indistinguishable if a narrower interval of values within the zones is applied.

Распределение составляющих ГТКк на рис. 1
Distribution of HTCc components in Fig. 1.

Area designation	Tangential component	Radial component
1 (1.2)	1,6–1,4	285–329
2.1	1,4–1,2	265–295
2.2	1,4–1,2	295–344
3.1	1,2–1,0	225–267
3.2	1,2–1,0	267–312
4.1	1,0–0,8	230–269
4.2	1,0–0,8	269–310
5 (5.1)	0,8–0,6	234–280

Another example of the application of GTCc when it is displayed on a small-scale map is shown in Fig. 3. The map "Hydrothermal coefficient for vegetation period" developed by a team of authors (Afonin A.N., Lee Y.S., Lipi-

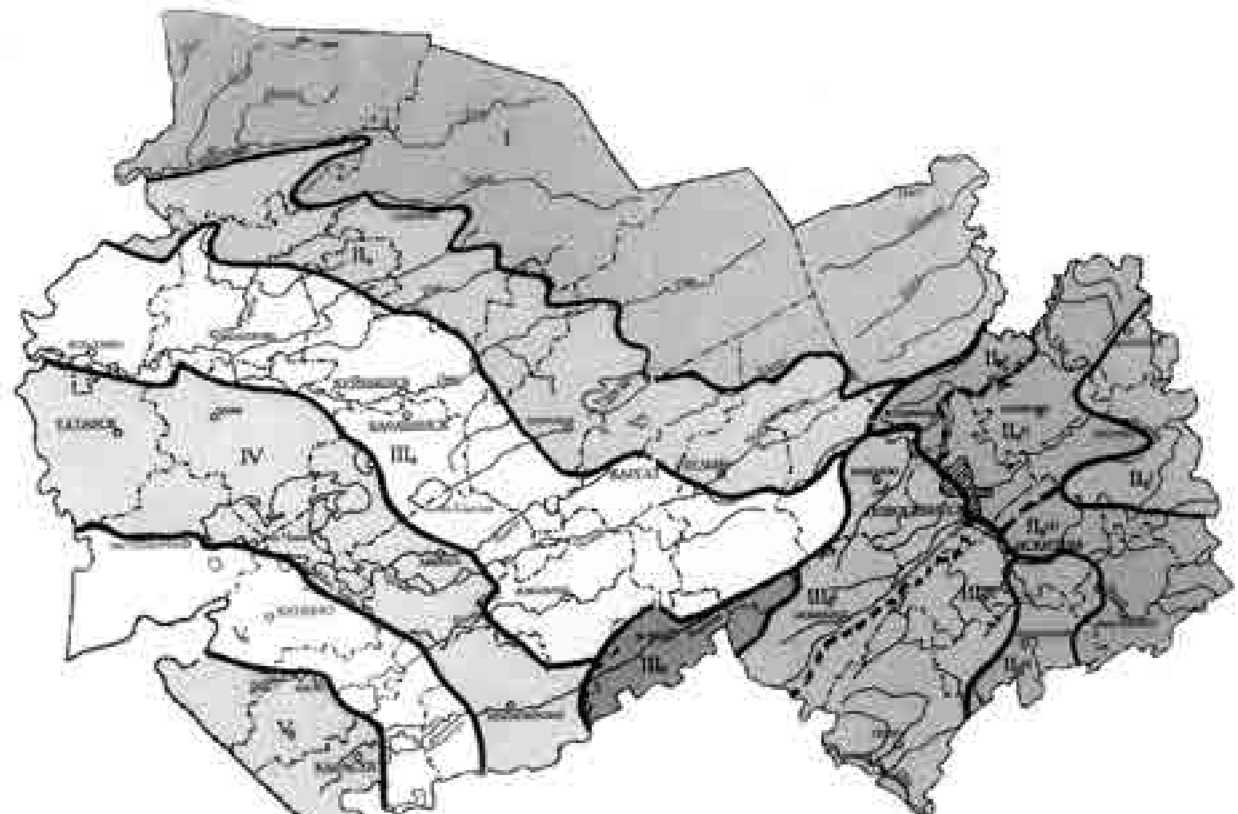

Рис. 2. Агроландшафтное районирование Новосибирской области:
I; IIa; . . .; Va; Vб – индексы агроландшафтных районов

Fig. 2. Agrolandscape zoning of the Novosibirsk region:
I; IIa; . . .; Va; Vb - indices of agrolandscape areas

yainen K.L., Tsepelev V.Yu.) is used as the basis in Fig. 3.[3]

On this map, the bold line indicates a strip of land along the meridian of 120 degrees, which corresponds to the interval of the Selyaninov HTC in the range from 0.7 to 1.3. The calculation carried out allows us to subdivide the selected band into four zones (with a thin line). Zone 1 corresponds to the average value of the radial component equal to 70.5; 2 - 99; 3 - 127 and 4 - 155. Thus, the strip of land, which has the same HTC Selyaninov interval and, consequently, the same degree of moistening, is subdivided into areas with different radial components and different climatic possibilities, as it should be expected when moving along the meridian from north to south. The HTCc describes the real situation of the territory in more detail (in terms of climatic conditions) and allows identifying the territorial divisions most suitable for certain economic purposes.

The transition to an integrated HTCc also provides an opportunity to estimate the spread of certain plants into new areas under increasing warming. The seemingly simple assumption that plants will seek locations where climatic conditions will be more favorable leads to a difficult question: what are these favorable conditions for plants in quantitative terms? To answer it, we should refer to the work of A.R. Konstantinov (see footnote 2). Studying winter wheat yield, he showed on experimental material that the yield value (hence, the level of development of this plant) depending on weather conditions graphically represents a set of decreasing in size quasi-ellipses. Each value of the yield corresponds to a closed line in the form of a quasi-ellipse. Moreover, the higher the yield, the smaller the quasi-ellipse; at its maximum value the closed line turns into a point. Although A.R.

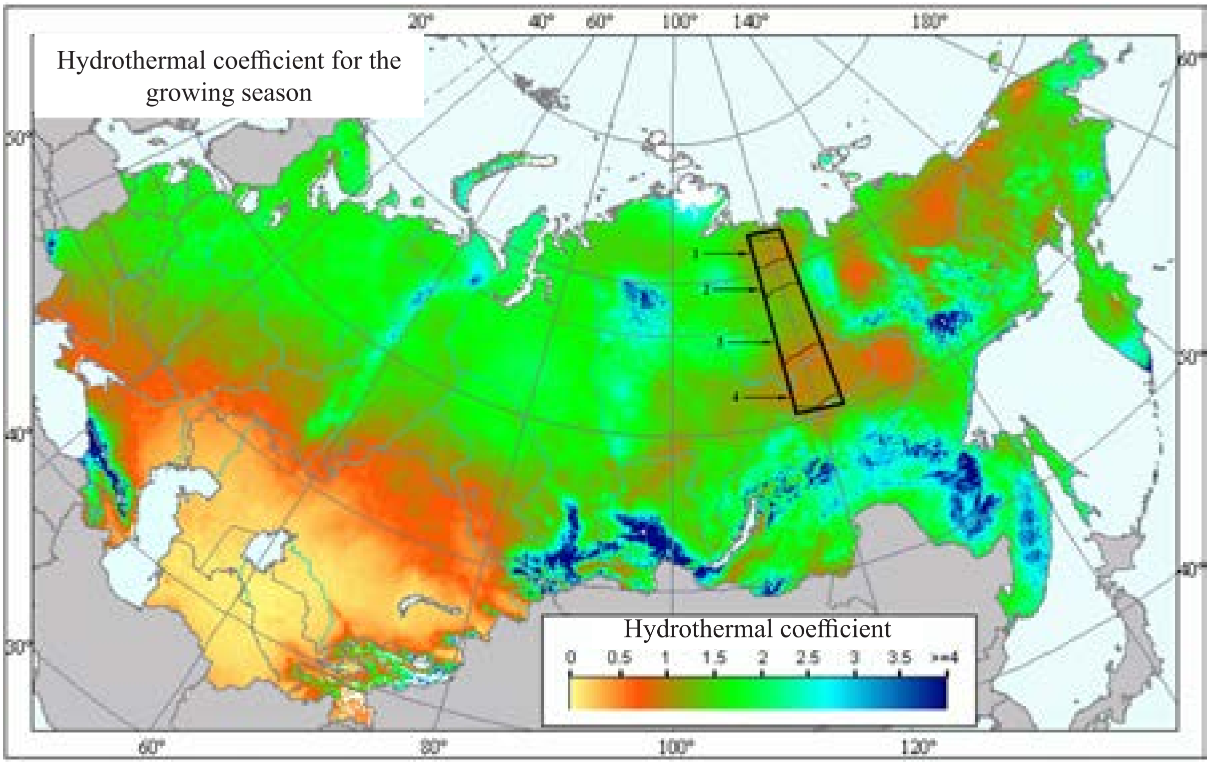

Рис. 3. Распределение радиальной составляющей ГТКк в выделенной полосе:
1; 2; 3; 4 – номера зон, сформированных относительно радиальной составляющей ГТКк
Fig. 3. Distribution of the radial component of HTCc in the selected zone:
1; 2; 3; 4 - numbers of the zones formed relative to the radial component of the HTCc

[3]Агроэкологический атлас России и сопредельных стран. Климат, Гидротермический коэффициент за вегетационный период: [Электронный ресурс]: URL: http://www.agroatlas.ru/ru/content/Climatic_maps/GTK/GTK/index.html. (дата обращения: 08.04.2020).

Konstantinov did not mention it, but it is easy to assume that this point corresponds to the optimal values of weather (climate) factors. It is especially important that each phenological phase (or interphase period) corresponds to its own set of quasi-ellipses and its own point of optimal factor values.

A.R. Konstantinov chose temperature (*t*) and absolute air humidity (*e*) as weather factors. In his calculations he used the average values of the factors for the interval of phenological phase of a plant (or for the selected interphase period).

Taking into account that air humidity e is considered in A.R. Konstantinov's work as a value suitable for characterizing water consumption conditions of plants, and that precipitation is the main reason for formation of air humidity, then transition from average air humidity to average precipitation value will not lead to principal change of graphs and will allow determining average optimal values of temperature and precipitation for each phenological phase based on newly constructed graphs.

I have performed an elaboration that offers an analytical model of yield (or level of plant development) based on four statements:

– yield losses are proportional to the deviation of weather (or climatic) factors from their optimal values;

– cumulative losses from two or more factors determines the vector sum of losses on individual factors, represented by orthogonal vectors;

– dependence of total loss value (in graphical representation) on weather and climatic factors represents a set of increasing ellipses for each phenological phase. Each set of ellipses has a turn by a certain angle, which in the analytical formulas is taken into account by the introduction before the factors of co-multipliers in the form of cosine or sine of a particular angle;

– the yield or level of development of the plant is defined as the difference between the maximum possible and real losses.

In fact, the third position is mainly a consequence of the first two, given in analytical form, supplemented by the peculiarity of the real situation in the form of the necessity to rotate the ellipse by a specific angle. The fact that the summation of two orthogonal vectors often leads to the formation of an ellipse will be demonstrated by a simplified example. Let the two vectors x_1 and y_1 have their origin at the zero point of the coordinate system, i.e., the point of optimal factor values is located at the beginning of the coordinate system. As a result of summation, we have a vector of length $R_1 = \sqrt{x_1^2 + y_1^2}$. Often in the real situation the summands of the vector have different scaling. In accordance with this we replace y_1 with kz_1 and obtain $R_1 = \sqrt{x_1^2 + (kz_1)^2}$.

Squaring the left and right parts of the last expression and dividing all the terms of the equation by R_1^2, we get:

$$\frac{R_1^2}{R_1^2} = \frac{x_1^2}{R_1^2} + \frac{k^2 z_1^2}{R_1^2}$$

or

$$1 = \frac{x_1^2}{R_1^2} + \frac{z_1^2}{R_1^2/k^2}.$$

The last expression is the classical equation of the ellipse, taking into account that $R_1^2 = a$, a $R_1^2/k^2 = b$, and taking into account that for the same length R_1 of the total vector different arbitrary values of x_1 and z_1 can correspond. Rotation of coordinate system or corresponding rotation of ellipse by a given angle and transfer of initial point of vectors will not basically change anything, but only lead to some difficulties in obtaining the same result.

The analytical form of the model is constantly being improved, sometimes undergoing significant changes. Recently a variant has been presented in which the factor "precipitation" has been replaced by the factor "soil moisture"[4] derived from it. Graphical constructions concerning weather conditions made by A.R. Kon-

[3]Agroecological Atlas of Russia and the Neighboring Countries. Climate, Hydrothermal coefficient for the growing season: [Electronic resource]: URL: http://www.agroatlas.ru/ru/content/Climatic_maps/GTK/GTK/index.html. (accessed 08.04.2020).

[4]Patent No. 2,733,728. Method of estimating the yield of spring wheat depending on weather conditions. Moscow: State Register of Inventions of the Russian Federation, 2020; Bulletin No. 28.

stantinov in the course of experimental studies are in good agreement with the proposed provisions of the model. It gives grounds to expect with high enough probability correspondence of provisions to real natural phenomena and on this basis to use identified properties and peculiarities in the following way. Each phenological phase corresponds to average values of temperature and precipitation factors, which can be calculated using the residual method outlined in the work of A.R. Konstantinov. It should be noted the rationality of combining very short phenological phases with their neighbors because of their probable instability, thus forming interphase periods. Hereinafter, the mean annual interval of the phenological phase and the mean annual interphase period will be referred to as the analyzed interval, which has the value n_i, where i is the number of the measuring interval, according to the number of days included in it. Knowing the duration of the analyzed interval n_i and the average value of the factor, it is easy to go to the following integral values:

$$S_{p_i}^{\text{plant}} = p_{\text{cp}_i} \cdot n_i$$

$$\text{и } S_{p_i}^{\text{plant}} = t_{\text{cp}_i} \cdot n_i.$$

Then, using techniques typical for polar coordinates, we get

$$\text{tg}\, a_i^{\text{plant}} = S_{p_i}^{\text{plant}} / S_{t_i}^{\text{plant}}$$

and the radial indicator

$$r_i^{\text{plant}} = \sqrt{\left(S_{p_i}^{\text{plant}}\right)^2 + \left(S_{t_i}^{\text{plant}}\right)^2}.$$

Thus, the plant under study has a set of pairs of indicators, which is equal in volume to the number of analyzed intervals.

Then we proceed to the climatic characteristics in terms of temperature and precipitation for the warmed area. We select analyzed intervals corresponding to the selected plant (or plant variety), and calculate complex HTCc for these intervals. Thus, we obtain a set of indicators similar to the first set for the plant under study. On the one hand, we establish plant requirements to climatic factors, which provide the maximum possible level of plant development, on the other hand, we obtain real climatic conditions in the form of similar indices, represented by complex HTCc. According to the closeness of the data in the sets, the level of plant propagation favorability (from climatic positions) is evaluated. It is estimated on the basis of the mean-square criterion of closeness of the sets or more simple variants are applied: for example, the maximum level of favorability is recognized if the average level of deviation module in the sets does not exceed 12% and the maximum deviation is less than 26% (when deviations are measured in percentages), etc.

CONCLUSION

The hydrothermal coefficient (HTC) of G.T. Selyaninov has been improved. A complex HTCc, represented by tangential (HTC*t*) and radial (HTC*r*) components, has been obtained. The new HTCc allows obtaining more detailed and complete information on the climatic situation of the territory, which is demonstrated by large- and small-scale graphical constructions. In fact, the complex HTCc compared to the previous variant allows increasing the volume of obtained information about the studied territory by about 2 times. As a variant of more complex application of HTCc, the study of the progression of a particular plant to new territories in the case of climate warming is presented. In addition, in the future we can expect with great probability the application of HTCc in breeding (to reduce the duration of the breeding process in crop production), farming (to reduce costs when solving land typing problems) and some other directions.

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