Protection of cereals from a complex of diseases

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Abstract. In this article lays the foundation for a program to protect various crops from a complex of diseases. The program is open for inclusion of new modules. As basic components, it uses previously developed models to protect wheat from brown rust, powdery mildew, Septoria and their complex. The new program has increased the detail of calculations based on the model of large-scale distribution of brown rust uredospores in wheat. Significant changes have been made to the basic module for protecting wheat from brown rust, which uses the results of calculations based on a large-scale spread model with a reduced space step and is the basis for comparison with other diseases. The new program was also adapted for the case of poorly defined initial conditions about the actual defeat of wheat by brown rust, powdery mildew and Septoria. Equations are given for estimating wheat damage and crop losses if there is no data on varietal characteristics, regardless of the phase of plant development.

1. Introduction
Russia is a grain power. An important role in preserving and increasing grain yields belongs to plant protection, which is complex, multi-factor and multi-variant. The economic component of any grain producer directly depends on the success of protective measures. This article presents a modified and expanded version of the program "wheat Protection from complex diseases" [1]. This approach makes it possible to assess the risk of simultaneous development of several diseases (not only on wheat) at the program level, which is an urgent task both from the point of view of the concept of digitalization of various fields of activity adopted in Russia, and in terms of improving the quality of phytopathological forecasts. This is a good basis for assessing possible crop losses and choosing the right protective measures for its preservation. The modified version, which allows for the real possibility of including information about other crops, received a new name "protection of grain from a complex of diseases". A complex is a set of processes that have a common purpose. The mutual influence of different diseases on each other is not considered.

2. Methods and materials
The program "Protection of grain from a complex of diseases" includes 5 more programs-3 advisory systems - "Protection of wheat from brown rust" [2] (new version not published), "Protection of wheat from powdery mildew" [3], "Protection of wheat from septoria" [4], "Protection of wheat from diseases..."
"[5] and the calculation model "Large-Scale distribution of uredospores of the pathogen of brown rust of wheat" [6,7] on a grid with a 150-kilometer step in space. All programs use the Delphi language.

Two basic advisory systems out of three related to the development of various wheat diseases remained unchanged: "Protection of wheat from septoria" [2] and "Protection of wheat from powdery mildew" [3]. The third - “Protection of wheat from brown rust" [4] has undergone significant changes and additions related to the general philosophy of building the program and the addition of a reference system. Common features of all 3 basic programs are based on extensive experimental data on methods of diagnosis, consideration of the etiology and epiphytotiology of a specific pathogen, the development of each disease in the spring and summer period, methods for organizing agroecological and phytosanitary events, measures to protect wheat from a specific disease, and methods for assessing crop losses. The decision to apply a certain type of protective events (processing with chemical fungicides, processing with biologics, waiting mode with subsequent monitoring of the development of the disease and termination of observations due to the absence of a threat) is made on the basis of comparing the actual degree of wheat damage by a particular disease with the level of phytosanitary signal damage (PSD). Most of the necessary parameters, their presence and specific value can be selected by the user after a dialog with a specific program. These include information about: 1) the fact of detection of a particular disease on crops, 2) the fact of using protective sprays, 3) the type of drugs and the number of days after treatment, 4) varietal resistance, 5) the presence of a number of factors that increase the disease, 6) the favorable weather conditions for the development of a particular pathogen, 7) the size of the planned crop and a number of other factors. In the interactive mode, the consumer adapts the advisory system to suit themselves. All 3 advisory systems issue a decision with one of the 4 formulations:

- it is necessary and economically feasible to spray crops with chemical fungicides,
- it is advisable to spray crops with biologics and resistance inducers as a preventive measure; observations should be continued,
- protective spraying is not appropriate; phytosanitary surveillance can be discontinued,
- do not carry out spraying, continue phytosanitary observations, and return to the advisory system again if the degree of disease development increases.

Only one parameter is provided for entering values – the degree of wheat damage by a specific pathogen - septoria, powdery mildew, or brown rust. All 3 basic programs can function separately. This approach is justified in the case of a noticeable prevalence of one of the diseases and favorable conditions for its further development. If the differences in the degree of wheat damage by different pathogens are close in magnitude or are within the error of its determination (no more than 10%), then all diseases must continue to be compared in order to obtain a solution that is adequate to real conditions.

To do this, all 3 diseases are first compared by the value of the phytosanitary signal lesion (PSL) in the corresponding phase of plant development. Each of the programs provides for entering values of the degree of wheat damage ( % ) by 3 diseases simultaneously and comparing them by the size of differences. The prevailing disease is considered as the main threat to crops if its degree of damage has changed little before the next accounting, but again exceeds the incidence of other diseases. Further work is being done on this predominant disease. If the differences are insignificant, then the comparison continues in terms of the amount of crop losses from each disease in material terms, even if another pathogen has started to predominate in wheat. To do this, go to another module (program) and work in it. Crop losses (in C / ha) are calculated using empirical and statistical ratios, and then converted into monetary form. If the situation has changed again during the next accounting, then in case of obvious differences, the decision is made on the prevailing pathogen. If all diseases are still difficult to distinguish even by the amount of losses from crop losses, and the levels of wheat damage by different pathogens exceed the corresponding values of phytosanitary signal damage (PSD), then their threat to wheat is joint and the decision on the type of protective measures is made taking this fact into account. The three basic advisory systems are ignored at the final stage of complex combined infestations, and the decision formulation is given from the main grain protection program.

The program "Protection of grain from complex diseases" also provides for the possibility of moving to the consideration of the features of the manifestation of diseases and measures to combat them in
various regions of Russia. For this purpose, a model of large-scale distribution (long-range transport) of wheat brown rust uredospores is used, which allows calculating the degree of plant damage by this pathogen over a large area (2500x2500 km) simultaneously. The model is based on the results of an objective analysis of the wind speed components u and v of the hydrometeorological center of Russia and experimental data from All-Russian Research Institute of Phytopathology. Calculations are performed using a complete 2nd-order differential equation (mass balance), which is solved numerically using the run-through method:

\[
\frac{\partial \Phi}{\partial t} = -(u(x, y, z, t) \frac{\partial \Phi}{\partial x} + v(x, y, z, t) \frac{\partial \Phi}{\partial y} + w(x, y, z, t) \frac{\partial \Phi}{\partial z} + \\
+ K_s \left( \frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial y^2} \right) + K_z \frac{\partial \Phi}{\partial z} + F + R - S;
\]

(1)

\[
\Phi = 0 \text{ on } z = 0;
\]

\[
\Phi = 0 \text{ on } z = H;
\]

(1.1)

\[
\Phi(x, y, z, 0) = \Phi_0(x, y, z);
\]

(1.2)

where \( \Phi \) - the concentration of inoculum in the atmosphere PCs / m³,

\[ u, v \] - the horizontal components of wind speed (m / s),

\[ w \] - the vertical speed (m / s),

\[ K_s \text{ and } K_z \] - the coefficients of horizontal and vertical diffusion, respectively,

\[ F \] – additional admixture to the atmosphere,

\[ R \] - loss of inoculum due to wet removal,

\[ S \] - "loss" due to a decrease in the infectious ability of the pathogen,

\[ H \] - the height of the upper boundary of the transport of spore clouds.

Equation (1) with initial conditions (1.1) and (1.2) was solved numerically by the run-through method.

The upper limit of rust uredospore transport is 1.5 km, and it was assumed that the pathogen concentration \( \Phi = 0 \) on this level and on the lateral borders of the calculation area.

Analytical relationships between the features of brown rust uredospore transport are performed on a statistical basis. The result is obtained at points in a regular grid with a step of 150 km. Then, the calculated values of the spore concentration at the level of the grass stand (1 m) are translated into the brown rust infestation of wheat, which is the main input parameter of the basic program "protection of grain from brown rust". If there is no observer in the field (there is no field data), then the necessary data on wheat infection with septoria and powdery mildew in the corresponding regions should be obtained using any available sources of information: mass media, publications of various state bodies, etc.

3. Results and discussion

The program of large-scale distribution (long-range transfer) of brown rust uredospores has been significantly reworked. The main goal was to reduce the space step from 150 km to the size of a normal wheat field of 1-3 km. In the new version, the space step is reduced by 4 times to 37.5 km, which significantly complicated the program and all the auxiliary routines for it. This also led to the need to create a new program to recalculate all the original arrays of horizontal components of wind speed \( u, v \) from 15x15 to 57x57. The values in the nodes of the new calculation grid and in all arrays with the original data are calculated using the "Prima" program. In it, some static arrays are converted to others according to certain rules with an increase in size first from 15x15 to 29x29, and then to 57x57. Then all newly created arrays are passed to a separate directory, from where they are read into the large-scale distribution program.

When calculating using this program, it was possible to significantly reduce the calculation error and improve the detail of the visual representation of data on the development of wheat diseases. The average
calculation error on the 57x57 grid was ~ 19.7%, while the same error for the 15x15 grid exceeded 30%. This is due to the fact that the grinding of the grid led to a decrease in the distance from most of the new nodal points to the points of the actually observed values of the uredospores of the wheat brown rust pathogen.

Among the unfavorable factors, we should note a significant increase in the cost of computer memory for storage and mathematical operations with large data sets. The occupied memory of each of the 30 auxiliary arrays increased from 4,500 MB to more than 100,000 MB, which significantly increased the requirements for the size of the computer's RAM.

A number of significant changes were also made to the program for calculating the primary damage to wheat by brown rust. This is the main input parameter of all basic programs when choosing the best ways to protect crops and determine crop losses. In the absence of information about the varietal characteristics of wheat, a certain generalized idea of them in an analytical form comes to the fore. The use of foreign sources proved to be very difficult. And here's why. Starting from the first works on forecasting the development of various types of rust, it became noticeable that foreign authors rely on the use of a number of values, the use of which was first in the USSR, and now in Russia is very limited. For example, in [8,9,11,12,13,14,15,16], the following input values are used: the duration of the dew period, the average minimum and average maximum air temperature, the mycelium growth function, the growth rate of the cumulative number of spores over crops, their weekly number, and a number of other parameters. The main forecasting methods are regression equations or 1st-order differential equations.

The final result is presented in the form of 2-4 complex nomograms, large tables or computer models based on narrowly specific information that is difficult for us to reproduce in real conditions. With rare exceptions, for example [10]. For the authors, the percentage of leaf damage by yellow rust is represented as a cubic dependence on air temperature, and the free term depends logarithmically on the duration of the wet period. This data can be used in some way, but otherwise there were very few suitable options. In our Advisory systems, we do not apply most of the previously specified parameters, which does not indicate a deterioration in our prognostic conclusions. Another set of initial values is also associated with differences in agroclimatic conditions in Russia and Western Europe or the United States, with the characteristics of cultivated varieties, the composition of pathogenic complexes, the economic and economic ability of agricultural producers to obtain fairly rare specific information, and a number of other historical conditions. In Russia, everything is different.

In the program "Protection of grain from a complex of diseases", a situation was implemented when an observer is absent when calculating a large area, that is, we do not have accurate results of field observations. In the initial version, data on infestation were calculated for 3 types of resistance of varieties to brown rust-for resistant varieties, moderately susceptible and susceptible. If there is no information about the varietal characteristics of wheat, an equation for calculating the primary appearance of brown rust on plants was obtained based on the results of long-term experiments:

\[ R = 9.76 \exp[-0.02(t-23)^2] \left[ 1+\exp(-0.36d+3.4) \right] \ln(x_o+1) – \\
(1+ 7(1 + \exp(9.25 – 0.19n))^{-1}) [1.23 – 0.615\exp(-0.0008(n-35)^2)]; \]  

where \( R \) - the intensity of brown rust accumulation (pustules/leaf), which is then converted to the lesion level in\%,
\( x_o \) - the density of inoculum deposition on the horizontal substrate (g / ha), and then the weight values are converted to quantitative values,
\( n \) - the number of days from the date of renewal of spring vegetation to the date of infection,
\( d \) - the duration of the drip - liquid period after spores hit the leaves (hour),
\( t \) - the average temperature of the wet period.
All the necessary information can be obtained using meteorological sites and official regional information sources. To translate primary infection into percentages, we use empirically selected coefficients for different phases of wheat plant development.

Next, the duration of the incubation period is calculated

$$\sum_{i=0}^{\tau} (t - 2) \geq 135.0 \quad (3)$$

Here $\tau$ is the duration of the incubation period, $t_i$ - the average daily air temperature.

And then an equation is made for predicting the development of brown rust:

$$\ln\left(\frac{y(t)}{100-y(t)}\right) = \ln\left(\frac{x_o}{100-x_o}\right) + zt; \quad (4)$$

here $t$ - the forecast lead time in days, $x_o$ - the degree of plant damage on the forecast date (%), $y(t)$ - the predicted degree of plant damage $t$ days after the forecast date ( % ), and $z$ - the rate of infection growth

$$z = -0.21 L \exp(-0.742 i^2); \quad (5)$$

where $i$ - the index of favorable weather conditions in the tubulation phase, $L$ - the coefficient that takes into account the degree of susceptibility of the variety to brown rust, which has 3 empirical values. For susceptible varieties, these values are 0.9-1.0, for moderately susceptible varieties - (0.55-0.6), for stable-(0.12-0.14).

The model was tested for 57 dynamics of brown rust development in different agroclimatic zones of Russia and showed a good correspondence with the actually observed values of the lesion. Correlation coefficient = 0.87.

Despite the 4-step nature of this forecast, it turned out to be convenient for a set of input parameters that can be quickly obtained from available sources. In addition, based on the relations (4) and (5), equations for determining crop losses in any phase of plant development were obtained, which were also applied in advisory systems:

$$\ln\left(\frac{y}{a-y}\right] = 0.26 \ln(x) - 0.03E - 1.3 i; \quad (6)$$

where $y$ - yield loss ( % ) $x$ - disease severity on the date accounts (%), $E$ - phenological phase of development of the wheat on the posting date (index on a scale Eucarpia), the $i$ - table index of the favorability of weather conditions, and is an empirical threshold crop losses depending on susceptibility of the variety that has only 2 values 0 and 1.

Multi-layered does not violate the harmony of the earlier logical constructs and almost no effect on the cost of computer memory and time for decision-making about the type of protective measures.

The economic effect of the program "Protection of grain from a complex of diseases" is achieved by carrying out the correct protective measures, which are regulated in detail for each disease and for their complex. The preserved crop with the use of fungicides averaged at least 5-10 C/ha.

The use of new approaches allowed expanding the variability of model calculations for most regions of the European part of Russia. It should be borne in mind that the original 15x15 grid (space step = 150 km) is part of another grid with dimensions of 55x47 points, which includes the whole of Russia, the Middle East (areas of the infection reservation), Central Asia, Southern and Eastern Europe and North Africa.

Unfortunately, work on further reducing the space step had to be suspended. The main obstacle was the computing power of the computer, which was not enough for calculations when reducing the step to 20 km or less. A computer with a Core i7 - 2600 processor (3.40 GHz) and 16 Gb of RAM could not perceive the entire task, and splitting it into smaller subtasks has not yet given the expected effect and requires further consideration. Working on a 55x47 grid is very difficult even with a 150-kilometer
space step. The immediate prospect is to optimize a number of components of the program "Protection of grain from complex diseases" and its visual interactive and cartographic implementation.

4. Conclusion
The research made it possible to draw the following conclusions:

1) a program of the general format "Protection of grain from a complex of diseases" was created, open for its further expansion by connecting new modules,
2) the program "Protection of wheat from brown rust" was significantly modified and significantly expanded, and installation files of this program were created for 32-and 64-bit computers,
3) the model of large-scale (long-range transport) of urediniospores of brown rust was rebuilt for calculations with a new step in space, which was reduced from 150 km to 37.5 km, and the whole complicated model was adapted to all the necessary modules of the program "Protection of grain crops from a complex of diseases",
4) developed equations for estimation of infestation of wheat crop losses in the absence of information about the varietal characteristics of plants in any phase of their development.

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