The use of mathematical modeling tools to predict the yield of genetically modified crops

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Abstract. Despite the high-tech innovation level of cultivation and processing, damage by insects - pests, is still high. In this connection, a sense of urgency growing new genetically modified (GM) varieties agricultures containing the gene of the soil bacterium called transgenic or genetically modified. This article explains the importance of mathematical modelling for the cultivation of GM crops.

1. Introduction
Genetically modified plants are of great practical importance and are of scientific interest. The spatial heterogeneity of the distribution of insect pests is one of the most intensively studied areas of theoretical biology and mathematical modeling. This phenomenon is widespread in nature; in fact, it would be difficult to imagine an ecological system uniformly distributed in space [1]. Spatial heterogeneity can be caused by various reasons [2]. The development of new methods of mathematical modeling to solve the problem of predicting the dynamics of genetically modified populations, including a set of interrelated models, their numerical implementation in the form of software packages based on the direction of population movement, slowing effects and the types of their interaction are an important problem in the field of mathematical modeling of complex systems and are of interest to a large area of research. Currently, methods inspired by natural systems are widely used in almost all fields of science and technology [3]. The increase in the production of genetically modified (transgenic, or Bt - by the name of the bacterium Bacillus thuringiensis gene introduced into plant tissue) crops that are toxic to pests determines the relevance of studying the long-term effects of using gene technologies based on modern mathematical models, numerical methods and program complexes.

2. Description of the problem
There is an applied problem of using transgenic crops to suppress insect pests in the field is the need to reduce the risk of pests adapting to the Bt-toxin produced by transgenic crops, taking into account the limitations of the spatial configuration of the system and the above scenario, the High-Asylum Strategy is recommended for monitoring development of pest resistance to Bt plants. «High dose» means that the toxicity level of Bt plants is high enough to kill almost all the larvae. A small percentage of surviving (Bt-resistant) individuals should be suppressed by ghb ghtvto transgenic
fields or near special zones not modified by plants (shelters), which are the source of Bt-susceptible individuals, which when mated with Bt-resistant should reduce the percentage of the last offspring.

One of the important problems of constructing models of the spatiotemporal dynamics of agricultural pests under the influence of a transgene is the lack of experimental values taking into account local climate conditions, soil and biological characteristics of the pest, etc. For example, the design features of the wings of meadow and stem corn moths do not allow them to move freely in space, like the rest of the «flying» insects. In particular, they cannot perform long flights and rarely rise high enough above the ground. As a result, the upper parts of plants are least affected by pests. However, this is not their only feature. Part of the pests transfers heat through the air, which in turn affects the formation of diffusion flows. In a number of problems [4], it is believed that the distribution does not occur throughout the space, but on the border of the region or on individual surfaces within it. This leads to the propagation of the wave mainly along these boundaries or, in any case, the propagation of the wave along the entire length is determined by surface phenomena. A similar situation arises in the ocean, where the spread of a number of species occurs only in the surface layer [5, 6].

Such objects in Russia and abroad were studied by such researchers as Kostitsyn V.A., Svirezhev Yu.M., Pasekov V.P., Altukhov Yu.P., Tyutyunov Yu.V., Zhadanovskaya E.A., Arditi R., Abrahamson D., Wilensky U., Bourguet D., Chaufaux J., Séguin M., Buisson C., Hinton J.L., Stodola T.J., Porter P., Cronholm G., Buschman L.L., Andow D.A., Onstad D.W., Guse C.A., Spencer J.L., Peck S.L. and others. Moreover, in the works of foreign authors imitation modeling prevails; significant contribution directly to mathematical modeling of dynamics modified cultures were introduced by Russian scientists, including the Tyutyunov Yu.V. scientific school [1, 7].

However, despite success, biological control can be considered from the point of view of the lottery model (Myers, 1985) with unpredictable results [7]. Existing mathematical modeling methods and simulation systems do not take into account the effectiveness of «safe shelters», depending on their shape and distribution in space, the diffusion coefficient is estimated, which casts doubt on the stability and effectiveness of long-term predictions of such models. As a result, many questions arise that require further study of pest behavior. Ecological and demographic processes, as well as evolutionary transformations in a population undergoing a spatially heterogeneous wave regime, differ from what can be expected in the case of a uniform distribution of population dynamics [8].

The reason for the inefficiency of modern mathematical models, simulation systems and analytical methods for their study is that they do not allow tracking changes in the dynamics of other types of harmful organisms, which are more and more with a decrease in the distribution of competing species [9]. For example, the larvae of two types of pests feed on all aerial parts of the plant, but modified corn destroys only the offspring of one.

Attempts to completely remove the resistance of pests to transgenic plants have not yet yielded the expected results. T. Wilson and J. Tollefson of the University of Iowa (USA) tested transgenic maize lines producing Cry 3 Bt toxin crystals, usually produced by the bacterium Bacillus thuringiensis. Although some species had increased resistance to the Western corn bug, the degree of resistance was not high enough. The reason for this is that toxins are produced in chloroplasts, while larvae feed on plant roots, where there are virtually no chloroplasts. As a result, a significant portion of the larvae feeding on the roots of agricultural transgenic crops survived.

Classical diffusion models of mathematical genetics take into account the structure of the distribution of insect genotypes, while not being able to accurately predict the dynamics of their growth and distribution in space. The concept of K. Maser in combination with the approaches and methods of R. Fisher and S. Wright made it possible to evaluate the genetic parameters of the population in this particular environment and for the given structure of biogeocenosis, but it could not predict the direction and strength of the shifts of the genetic parameters of the population with changing environmental and genotypic conditions.

Known demo-genetic models such as «predator – prey» and «Pest – parasitoid» allow sufficiently effective investigation of the behavior and population dynamics of a particular pest species under the
influence of a transgenic plant, for example, Tyutyunov – Arditi – Zhadanovskaya models [10, 11] show that pest mobility plays a decisive role in the effectiveness of the «high dose – shelter» strategy due to the structure of the studied pest does not have sufficient mobility, and the migratory mobility of genotypes can vary significantly. Are described only by the presence of advective and diffusion flows, which is not enough for accurate prediction.

It is reasonable to assume that the easier it is for pests to get into «shelters», the faster they lose their resistance to poison and, in order to simplify the achievement of «shelters» by the pest as much as possible, we will reduce their size, maintaining a ratio of 20% of the main field. In work [10-13], the type of arrangement of shelters is considered when four sections of a square shape with «ordinary» corn are located in the center of the transgenic field, when at the border a) there is ordinary corn, b) transgenic. Figure 1 shows the dynamics of pests in four shelters.

The presence of «shelters» of different sizes and locations is justified only in the case of a large spread of heights in this section of the field. But in this case, the development of a three-dimensional model of the dynamics of pests will be required.

In figure 1 a) it is seen that at first plots with «ordinary» agricultural crops are eaten up, then - with transgenic and only after that are as that are inaccessible between them (highlighted in white). If the borders are from a transgenic variety, as shown in figure 1 b), the pests move directly from the «shelters» to the main part of the field (here the intensity of the palette from blue to red indicates an increase in concentration to the field borders). This is more clearly seen in figure 2.

The obtained result confirms our assumption that the distribution of «shelters» over the area of the main field should not touch the boundaries of the region, since otherwise we will reduce the likelihood of pests entering the «shelters».
3. Summary
Despite a significant number of publications, many of the effects that are important for improving the accuracy and reliability of long-term forecasts related to spatial heterogeneity of the environment, interspecific competition, taxis, slowing down and adaptation of plant resources were not taken into account in mathematical models.

The different concentration of plants on the field may depend on the following factors: processes with a lag effect characteristic of annual crops and causing uneven growth and development of plants, as well as spotting that occurs due to different sizes of transgenic and ordinary crops, their species and competition between them [11-13]. The development of effective mathematical models, modeling systems and analytical methods for studying them and obtaining sufficiently accurate predictions of the concentration of harmful organisms would reduce the cost of the crop.

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