Simulation model of crop yield on individual land plot

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Abstract. The modern stage of development of society is characterized by active use of software solutions in almost all spheres of life. The last decade has seen an active digital transformation of the processes of human professional, economic and household activities. In order to effectively implement such processes, tools are being developed that, for example, support decision-making, monitoring and quality management. In addition, routine technological operations are being robotized and automated. The agricultural industry is no exception. When developing software solutions for such industry, it is necessary to take into account the interests and resources of citizens who are engaged in growing products on individual plots of land. The paper defines the relevance of the development of a simulation model corresponding to the dynamics of yields on an individual plot of land. The key aspects of the issue are identified, to which the method of system dynamics is applied. As a result, a simulation model reflecting the changes in the states of plants on the plot, the speed of their transition from one state to another, as well as the parameters influencing them is created.

1 Introduction

There are 12.5 million garden plots and about 540,000 vegetable garden plots in Russia [Vedomosti: https://www.vedomosti.ru/society/articles/2024/08/13/1055375-rosreestr-opredelil-priznaki-neosvoennih-dachnih-zemel]. The difference between a garden plot and a vegetable garden plot is the possibility of construction of real estate objects (garden or residential houses, outbuildings and garages). On a vegetable garden land plot it is possible only to place temporary non-capital objects, which may include sheds, greenhouses, sheds and other objects that are intended only for the storage of inventory or crops.

According to surveys, 46% of Russians have a garden or vegetable garden plot, on which any work related to the cultivation of vegetables, berries, fruits greens and other crops is carried out [Public Opinion Foundation: https://fom.ru]. According to a global survey conducted in 17 countries, one third of respondents work on garden plots on a daily or weekly basis [GfK research: https://www.gfk.com/ru/press/issledovanie-gfk-rabota-na-sadovykh-uchastkakh-skolko-ehntuziastov-v-rossii-i-mire].

Over the past decades, the role of land plots in the social and economic sphere of Russian citizens has changed [1]. Predominantly for the population of villages and hamlets it is the main source of products obtained by personal labor of the family, for urban residents - it

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provides more complete satisfaction of material, housing, cultural and domestic needs, being secondary employment for able-bodied citizens [2].

To ensure effective activity on the land plot, infrastructure development (transport, utilities, etc.) takes place, methods of plant cultivation are improved, machinery is modernized, pest control means are developed, etc. For instance, biodynamic farming is becoming popular. In the basis of this practice, the land plot is considered as a single ecosystem. During implementation, there is a refusal of any chemical preparations, soil fertilization is carried out only with the use of organic fertilizers.

Modern trends related to the digital transformation of different processes have affected agriculture and ensure the development of the industry. Thus, the created software solutions help in decision making [3, 4], control unmanned transportation [5, 6], manage warehouse processes [7, 8], monitor the climatic condition in premises [9], etc. At the same time, numerical models are developed that make it possible to predict changes in the state of processes related to, for instance, topsoil degradation, crop yields [10]. Such models reflect the key aspects of the observed object (or process), making it possible to form a forecast of changes in its characteristics based on the rules existing in the natural environment [8, 11]. Models are actively used to create intelligent systems that make it possible to make decisions about changing current settings (for instance, a "smart farm" system) or notifying a specialist on the basis of real-time data [9, 12].

All of the above categories of digital developments are designed for operation in agro-industrial complexes or farms, and software solutions for citizens dealing with personal land plots are reference systems, systems of objective control over the condition of the plot or specific objects located on it, or a system of notification of works in progress. The creation of an intelligent system, which integrates all digital resources used on the plot, makes it possible to create a single mechanism not only to control the state of all processes, but also the possibility of receiving objective individual recommendations depending on the current conditions for the organization of agricultural activities. Thus, the practical significance of the research is determined. Theoretical significance lies in the systematization of data related to the peculiarities of growing crops for personal farming and the creation of a model of processes suitable for research related to sustainable development of rural areas.

For the accomplishment of the accomplishment of the objective, which is the creation of a simulation model of the yield of crops grown on a land plot, it is required to perform the objectives of identifying the key objects and processes affecting the yield of crops, to analyze and select methods of formalizing the results analysis and to develop an appropriate conceptual simulation model.

2 Methods

A simulation model, in its essence, is a digital twin of all those characteristics of a real object, the research of the state of which is the purpose of the work [7, 13, 14]. The analysis of the sources of relevant literature has shown that in order to obtain an accurate description of the characteristics of the subject area, it is necessary to use a set of methods based on structural analysis [10, 15, 16].

To apply the method of structural analysis, the methods of step-by-step refinement, systematization, synthesis and abstraction were jointly applied in the work. The complex application of the above methods made it possible to obtain a detailed description of the structure of interrelated processes and objects affecting their state. In addition, it was possible to form a set of key characteristics of the subject area, affecting the level of yield of the land plot.

The formalization of the obtained results was carried out using the method of system dynamics, which is a type of simulation modeling. Such a method is used for dynamic systems in which there is a functional dependence between time and the state of each element of the system [8, 10, 17]. Cultivation of crops on a land plot can be called a dynamic system, in which the change in the state of objects is carried out over time and depends on numerous factors, including random ones.

3 Result

The use of the stated research methods made it possible to establish the key characteristics affecting the yield of the land plot. Fig. 1 presents a model of system dynamics, which reflects the emerging processes of transition of key objects from one state to another, as well as the parameters that affect the speed of the corresponding transitions. For clarity of the image, the parameters affecting the transition are logically grouped relative to it.

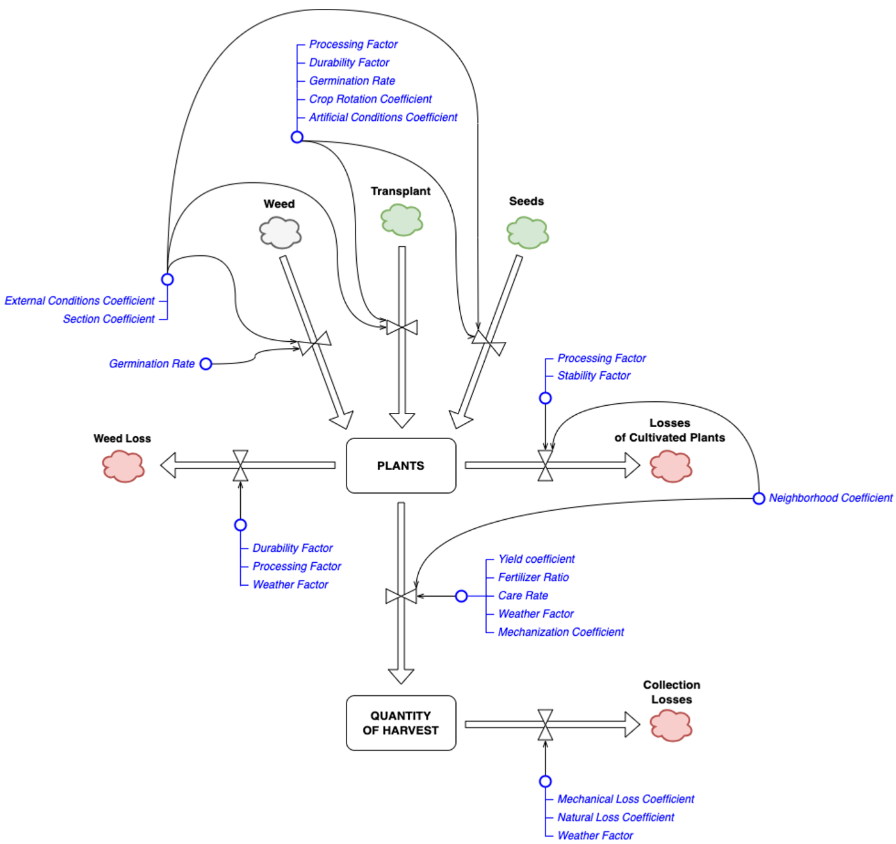

Fig. 1. Model of system dynamics of crop production on a land plot

The key object on a plot of land are cultivated plants, which can be in the seedling and seedling state. Over time, they change into the plant state, thereby creating a total mass of plants. Depending on the external conditions as well as the characteristics of the plant itself, they move into the crop state. If harvesting processes are disrupted, there will be some losses, which is reflected as an additional state.

In addition to crops, weed plants may occur on the plot (the way they get there and the form of their growth does not matter). Accordingly, when they develop, they too are included in the total mass of plants that grow on the plot. They can be removed in various ways and can continue to affect the growth and development of cultivated plants until harvesting.

The growth and development of any plant depends on external conditions, which include climatic and weather conditions, soil conditions on the site, natural biological conditions (for instance, growth timing, parasite resistance levels, yield levels) and artificial conditions that are directly created by humans. These conditions include plant proximity, planting density, crop rotation requirements, and frequency of activities related to the creation of favorable conditions (for instance, frequency of watering, weeding, fertilizing, shading). Accordingly, failure to comply with the conditions, poor quality work or the occurrence of random events (for instance, weather changes) can lead to the loss of any plants. It should be taken into account that works aimed at weed control may cause damage and loss of cultivated plants.

The model also considers losses of the finished crop. Such losses may occur due to long downtime of plants on the plot (for instance, failure to meet the harvesting dates due to unfavorable weather conditions) or technical problems (for instance, failure to follow the harvesting methodology, wrong settings of machinery during automated harvesting).

The developed graphical model of system dynamics of land plot yield can be transformed into a system of parametric equations, according to the methodology of simulation modeling. Part of the parameter values for the functions is determined by formulas and tables from the reference literature on agronomy or characteristics of the corresponding plant (for instance, yield coefficient, neighboring plants), the other part should be added by the user, as it is directly related to the characteristics of the individual plot, works carried out on it, plants planted and yield objectives.

4 Discussion

Simulation modeling is actively used in various industries (for instance, project management [16, 18], transportation systems [14, 15], ecology [3, 19], logistics [7, 8]), primarily due to the development of computer science. In order for the developed model to be adequate to the subject area and the results obtained with its help to be valid, an analytical design stage is required, taking into account the polymorphism of the real system [12, 17]. The use of the stated methods made it possible to establish the input and output parameters of the model, as well as the rules for their transformation. The obtained results are valid, as they correspond to the nature of the results obtained in related research in which such a set of methods was applied [10, 13, 15].

The transformation of the results obtained at the analytical stage, according to the system dynamics methodology, meets the requirements of simulation modeling. This is due to the fact that in the formalized model all structural elements representing the description of key aspects of the subject area are established. The established rules, the format of input and output data corresponds to the requirements for the objects of intelligent systems [3, 4, 12].

5 Conclusion

For a modern person, the use of software tools in professional activities or in everyday life is a commonplace. The activities carried out on a plot of land using such tools have advantages. The availability of a single digital solution makes it possible to optimize all processes related to the preparation, cultivation, harvesting and storage of crops. Optimization can be associated with numerous factors, including reducing labor costs, ensuring constant monitoring and control over the condition of the site as a whole or specific objects (including crops), improving the quality of products or increasing the efficiency of work performed.

References

1. 1. I.M. Kulikov, I.A. Minakov, Agrarnaya nauka Euro-North-East 1(56), 9-15 (2017)
2. 2. A.I. Chursin, I.H. Krivtsova, International Journal of Applied and Fundamental Research 1-2, 187-189 (2014)
3. M. Logachev, L. Krylova, E3S WoC 462, 02041 (2023) https://doi.org/10.1051/e3sconf/202346202041
4. A. Krasnikov, E. Romanova, O. Kireeva, BIO Web Conf. 83, 03005 (2024) https://doi.org/10.1051/bioconf/20248303005
5. A. A. Mironchuk, N. A. Ganja, Young Researcher of the Don 1(16), 64-67 (2019)
6. Y.N. Zubarev, D.S. Fomin, A.N. Chashchin, M.V. Zabolotnova, Bulletin of the Perm Federal Research Center 2, 47-51 (2019) https://doi.org/10.7242/2658-705X/2019.2.5
7. I.N. Krasnikova, V.L. Simonov, A.E. Petelin, BIO Web Conf. 83, 03004 (2024) https://doi.org/10.1051/bioconf/20248303004
8. O. Korotun, Ya. Nikulin, BIO Web Conf. 116, 07037 (2024) https://doi.org/10.1051/bioconf/202411607037
9. P.S. Obukhov, V.V. Demchenko, European Journal of Natural History 2, 83-87 (2021)
10. M. Logachev, D. Goncharov, BIO Web Conf. 93, 02015 (2024) https://doi.org/10.1051/bioconf/20249302015
11. S. Nosova, A. Norkina, O. Medvedeva, I. Aracelova, V. Grankina, L. Shirokova, Digital Technologies as a Process of Strategic Maneuvering in Economic Development. In *Biologically Inspired Cognitive Architectures Meeting*, 380-392 (Springer, 2021) https://doi.org/10.1007/978-3-030-96993-6_41
12. M. Logachev, V. Simonov, BIO Web Conf. **83**, 03002 (2024) https://doi.org/10.1051/bioconf/20248303002
13. G.S. Zhukova, Z.R. Radjabov, A.K. Kurbanmagomedov, G.V. Boykova, External impacts on structure and relaxation properties of thermotropic liquid crystal copolyester. In *IOP Conference Series: Materials Science and Engineering*, **905(1)**, 012074 (IOP Publishing, 2020) https://doi.org/10.1088/1757-899X/905/1/012074
14. A. Krasnikov, P. Mironov, E3S WoC **535**, 04007 (2024) https://doi.org/10.1051/e3sconf/202453504007
15. I. Krasnikova, I. Dyakonova, S. Grigoreva, E3S WoC **535**, 04002 (2024) https://doi.org/10.1051/e3sconf/202453504002
16. M. Logachev, M. Zelenkov, BIO Web Conf. **107**, 04023 (2024) https://doi.org/10.1051/bioconf/202410704023
17. V.V. Volkov, V.I. Erokhin, A.S. Krasnikov, A.V. Razumov, M.N. Khvostov, Computational Mathematics and Mathematical Physics **57**, 1757-1770 (2017) https://doi.org/10.1134/S0965542517110148
18. I. Nikishina, BIO Web Conf. **107**, 05015 (2024) https://doi.org/10.1051/bioconf/202410705015
19. I. Krasnikova, O. Mudrakova, E3S WoC **515**, 02024 (2024) https://doi.org/10.1051/e3sconf/202451502024