Model, algorithm and computer application for automated selection of varieties and hybrids of grain crops

A I Pykhtin¹, A V Gostev²

¹ Southwest State University, 94, 50 let Oktyabrya Ave., Kursk, 305040, Russia
² "Kursk FANTS" All-Russian Research Institute of Agriculture and Soil Protection from Erosion, 70b, Karla Marksa Ave., Kursk, 305021, Russia

E-mail: aipykhtin@swsu.ru

Abstract. Under the conditions of modern high-tech agricultural production, there is a need to develop tools contributing to the scientifically based selection of adaptive varieties and hybrids, considering agrotechnological and soil-climatic features specific for each individual agricultural system. Their development and further implementation in agriculture will contribute to stable and profitable yields of grain crops. Solving this problem, issues related to the definition of criteria that accurately describe the characteristics of the conditions and the degree of their impact on cultivated varieties and hybrids of grain crops are of great importance. The process of cultivar changing due to the changes of climatic, environmental, economic and other conditions is quite common in agriculture and therefore, there is an obvious need of agricultural producers for development of such software. As a result of the research work, a concise mathematical model, an algorithm, a database structure and software were developed to enable obtaining a list of most appropriate varieties/hybrids of main grain crops for the conditions of the European part of the Russian Federation on the basis of user-defined parameters (depending on the selected grain crop). The software was designed in the form of a Web-application accessible from any device connected to the Internet, and the program interfaces were fitted for personal computers, tablet devices and smartphones. The application allows flexible configuration to add new crops, varieties (hybrids) and parameters without changing the source code of the program modules.

1. Introduction

Getting stable, productive grain crops of high quality should be started with the selection of varieties and hybrids with high adaptive potential, able to withstand unfavorable factors. Besides, in the context of the development of adaptive landscape agriculture, varieties and technologies for cultivating agricultural crops should be different for each farm considering the elements of the microlandscapes [1], since the development of precision farming directly depends on the features of the microlief, agromicrolandscapes on each section of the field while applying agricultural technology [2]. Thus, for different categories of microlandscapes, varieties and hybrids of crops positively responding both to the conditions of growth and to the proposed agricultural technology should be cultivated. Therefore, in agrarian production, there is a growing need to create a rapid and objective assessment for selection of most appropriate seeds with the highest adaptability for growing conditions among the available varieties [3].

The selection of the most appropriate variety or hybrid of agricultural crops is a complex multifactor task that requires availability and application of specific, highly-specialized knowledge, as well as
experience in its practical application. Besides, periodic analysis of reference information on new varieties and hybrids allowed for cultivation in Russia and the results of the State Variety Testing in the proposed cultivation region is needed. In spite of the simplicity of the above factors, the risk of the wrong choice is high, resulting in both reduction of possible profit and some potential loss for agricultural production. At present, in most cases, a variety (hybrid) of grain crops is selected on the basis of successful marketing companies of distributors of originating organizations or patent owners, recommendations of regional agricultural committees and departments, as well as personal preferences of agronomists [for example, 4], while scientifically grounded analysis of different characteristics of cultivars [5-6] is not so common. Therefore, the objective of the research is to provide agricultural producers with correct and up-to-date information on existing varieties and hybrids included in the Register of Selection Achievements by developing an appropriate algorithm and software.

The first attempts to design such software modules within the applications for the selection of optimal agrotechnologies on the basis of specified parameters considering the territorial and sectoral specifics of agricultural holdings were made in Russia in [8-9]. But these developments considered only the specifics of the Kursk region of Russia, they were inflexible Windows-platform applications, and did not contain information about the most relevant varieties and hybrids of grain crops.

2. Proposed method

The system approach, the theory of database design, and mathematical modeling were chosen as research methods.

Let us propose a mathematical model for the selection of a variety (hybrid) of grain crops. Let there be a set of grain crops $C = \bigcup_{i=1}^{N_C} C_i$ (i = 1, ..., $N_C$), and a set of varieties (hybrids) of crops $G = \bigcup_{j=1}^{N_G} g_j$ (j = 1, ..., $N_G$). The correspondence of varieties and hybrids is given by matrix $S = (s_{ij})$, whose elements $s_{ij} = 1$, if the variety (hybrid) refers to the crop, and $s_{ij} = 0$ if not. Also, a set of parameters for the selection of varieties and hybrids $P = \bigcup_{k=1}^{N_P} p_k$ (k = 1, ..., $N_P$) is given. The use of parameters for the selection of a variety of certain crops is given by matrix $T = (t_{kj})$, whose element $t_{kj} = 1$, if the parameter is used to select a variety, and $t_{kj} = 0$ if not. The initial data for the decision are the vector of parameter values $\vec{x} = (x_1, x_2, ..., x_k, ..., x_{N_p})$. Also, for each crop $c_i$, variety $g_j$, and parameter $p_k$, function $F_{ij}(x_k)$ are given, presented in a tabular form which is a mathematical representation of an expert scientifically grounded assessment of the correspondence of values $\vec{x}$ to a particular variety (hybrid). An example of the initial data is presented in table 1.

Optimal varieties for crop $c_i$ for input data vector $\vec{x}$, are those to which the maximum value with the set relative tolerance $\varepsilon$ is:

$$\max_{g_{ij} \in G} \left\{ \sum_{k} F_{ij}(x_k) s_{ij} \cdot t_{kj} \right\}.$$  \hspace{1cm} (1)

To select optimal varieties, the following algorithm is proposed:

1. The database containing the list of crops $C$, varieties (hybrids) $G$, parameters $P$, matrix $S$, $T$, function $F_{ij}(x_k)$, tolerance $\varepsilon$ is formed.

2. The user chooses crop $c_i$, inputs value $\vec{x}$.

3. For all crop $c_i$ varieties (hybrids) $O_j = \sum_{k} F_{ij}(x_k) s_{ij} \cdot t_{kj}$ are calculated.

4. Maximum value of $O_{max} = \max_{j=1}^{N_G} (O_j)$ is determined.
5. Optimal varieties (hybrids) $g_j$ are those for which $\left| \frac{O_{\max} - O_j}{O_{\max}} \right| \leq \varepsilon$.

| Parameter $p_k$ | Parameter value $x_k$ | $F_{ij}(x_k)$ for variety $c_i = \langle\text{Spring barley}\rangle$ |
|-----------------|-----------------------|--------------------------------------------------|
| $p_1 = \langle\text{Purpose}\rangle$ | $x_1 = \langle\text{Grain-fodder}\rangle$ | 1 0 0 0 |
| | $x_1 = \langle\text{Malting}\rangle$ | 1 1 1 1 |
| | $x_1 = \langle\text{not specified}\rangle$ | 1 1 1 1 |
| $p_2 = \langle\text{Variety type}\rangle$ | $x_2 = \langle\text{Middle-early}\rangle$ | 1 0 0 0 |
| | $x_2 = \langle\text{Mid-season}\rangle$ | 0 1 1 1 |
| | $x_2 = \langle\text{Middle-late}\rangle$ | 0 0 0 0 |

The algorithm block-diagram is presented in figure 1. To implement the application for the selection of a variety (hybrid) using the theory of database design, an ER-model of the system was developed (figure 2).

3. Results and discussion

Based on this ER-model (figure 2), a database was created using a free MySQL DBMS. The software for the selection of a variety (hybrid) of grain crops is designed in the form of a Web-application using a high-level free PHP programming language. It should be noted that in addition to the main algorithm,
the program implemented a number of additional checks to screen out unacceptable solutions for the selection of a variety (hybrid), for example, if the crop chosen by the user is irrelevant for the region chosen by the user, a corresponding message is displayed and the user is asked to adjust the selection of the crop or region.

The program consists of 2 interfaces: administrative and operating ones. In the administrative mode, an authorized user can enter new crops, their varieties, parameters and other information necessary to determine optimum varieties (hybrids). In the operating mode, authorized users select the crop they are interested in, set the values of parameters, and obtain a list of recommended varieties (hybrids) with a description. The description is an html-document, which includes the name of the variety (hybrid), the year of the inclusion into the State Register of Selection Achievements, the regions of admission for the European part of the Russian Federation. In addition, there are originators and patent holders, visual differences in the structure of vegetative organs, average yields according to the results of the State Variety Testing, as well as the degree of resistance to diseases and pests. The Web-application is accessible from any device connected to the Internet, program interfaces are fitted not only for personal computers, but also for tablet devices and smartphones. The prospect for the development of the created software is the creation of offline versions for iOS and Android devices. The application allows flexible configuration for adding new crops, varieties and parameters without changing the source code.

The developed software was tested using a variety of different sets of data. The results of the testing were compared with the results obtained by the scientists-experts of the All-Russian Research Institute of Agriculture and Soil Protection from Erosion on the selection of varieties (hybrids) of grain crops used in software testing on the same sets of data. Part of the sets of input data is related to "obvious" variants, i.e. variants, for which decision of scientific experts was unambiguous and did not allow the omission of one or another optimal variety (hybrid). The results of the practical evaluation showed that in 98% of cases the program had solutions that coincided with the opinion of scientific experts for "obvious" variants. In 100% of cases the recommendations of the program did not find unacceptable decisions. In 92% of the cases for the "unobvious" variants, the program had solutions that scientists-experts estimated as acceptable.

Partial alternatives of the developed software are: 1) the electronic version of the State Register of Selection Achievements admitted to use in Russia, developed by the "State Variety Commission" (http://reestr.gossort.com); 2) the use of expert assessment by involved specialists in varieties and hybrids from relevant research institutes; 3) visiting scientific and practical seminars of the Ministry of Agriculture of Russia and subordinate organizations; 4) use of recommendations developed by specialized research institutes. Comparison of the developed program with the alternatives is presented in table 2.

4. Conclusion

Thus, the developed software available on devices connected to the Internet, based on the created model and algorithm, makes it possible to solve the problem of selecting the most suitable cultivars or hybrids of a grain crop quickly on the basis of parameters chosen by the user according to the resistance to unfavorable weather conditions, and the yield and the quality of the grain. That is, this is selection of a variety and a hybrid suitable for the specific soil and climatic and economic conditions, which will contribute to the increase in production profitability without a significant increase of total production costs. Further work on creating an offline version of the developed software, as well as expanding the possible functionality of the program, will expand the list of possible users and will promote more active implementation of scientific results in domestic agricultural production.
Table 2. Comparison of the developed software and alternatives

| Parameter | Proposed software | Alternatives | Application of recommendations of specialized research institutes |
|-----------|-------------------|--------------|---------------------------------------------------------------|
|          | State Register of Selection Achievements | Expert estimate of the involved varieties and hybrids | Attending seminars conducted by the Ministry of Agriculture of Russia and subordinate organizations |
| Possibility to get information about varieties and hybrids description | + | + | +/a |
| Possibility of optimal variety (hybrid) selection | + | - | +/-c |
| Possibility of distant selection of varieties (hybrids) | + | + | +/- |
| Approximate time required for the analysis of the available varieties (hybrids), h. | 0.5 | 2 | 2f |
| Estimate of probability of obtaining “prejudiced result” | low | low | high | middle | low |

a As a rule, experts do not know all varieties, are familiar only with some originators.
b Recommendations are updated seldom, do not include newest varieties and hybrids.
c As a rule, experts do not know all varieties, have good understanding of some originators.
d Only among crops, varieties and hybrids, discussed at the seminar.
e Recommendations are updated every few years, do not include newest varieties.
f Without including time required to find an expert.
g Without including time for the trip to the seminar.
h Without including time for searching for actual recommendations.

5. Acknowledgments
The research was carried out within the framework of the Grant of the President of the Russian Federation for the state support of young Russian scientists - candidates of sciences, No. MK-1064.2018.11.

References
[1] Abashev V D 2000 Farming on North-East drain lands (Kirov: Northwest Agricultural Research Institute)
[2] Ivanov D A and Rubtsova N E 2007 Adaptive response of agricultural plants to Nonblack soil area landscape conditions (Kirov: Northwest Agricultural Research Institute)
[3] Bome A Y and Bome N A 2007 Modern High-end Technologies 2 60-61
[4] Koreneva A 2018 How to make wheat varieties work for yields? https://agrobook.ru/expert/kak-zastavit-sorta-pshenicy-rabotat-na-uvozhay
[5] Radchenko L A and Radchenko A F 2017 Yield and quality of winter wheat in the steppe Crimea Tavria Agrarian Bulletin 1(9) 71-79
[6] Alabushev A V 2011 Variety as a factor of innovation development of grain production Grainfarm in Russia 3 1-8
[7] 2018 State Register of Approved Selection Achievements. V.1. “Plant Varieties” (Moscow: Rosinformagrotech)

[8] Pykhtin I G and Gostev A V 2014 Improvement of agricultural system and technologies in present-day conditions of farming *Achievements of science and technology in agribusiness* 4 79-80

[9] Pykhtin I G, Gostev A V and Pykhtin A I 2017 Software decision support in the cultivation of crops *Journal of Engineering and Applied Sciences* 20 5338-5342