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Predicting crop yield of triticale in the regions of Russia for the production of bread products using the CGMS system

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***Abstract*—Forecasting crop yields is important part for the agricultural development system of the country. The production and prediction of triticale yields have direct impact on national and international economies, and play an important role in the food management in Russia. In Russia, special attention is paid to the production of triticale by bakeries as an agricultural crop, surpassing other cultures in quantitative protein content and qualitative amino acid composition. The objective of this study is to investigate how we can best predict triticale yield during the vegetation period in Russia. The approach used in this study is based on a crop growth model which is able to quantify the effect of weather conditions on crop growth. The model focuses on predictors from Crop Growth Monitoring System (CGMS) and triticale crop yield data in 20 administrative districts of Russia.**

***Keywords*—forecasting, triticale, yield forecast, CGMS.**

I. Introduction

The idea of organizing food with the rejection of the flour, gluten-free diet, the consumption of simple foods with minimal heat treatment are being promoted everywhere today as the postulates of a healthy lifestyle. But what about the bread, the staple food of all times and peoples? Bread is made from cereal flour, contains gluten, is subjected to heat treatment in ovens. Is it possible completely abandon the consumption of bread or its equivalent replacement for another product? We think that this should not be done, because there is an alternative solution - the production of bread from triticale flour [4].

Triticale is the “crop of the future”, still undervalued in the baking industry [10]. Triticale (x Triticosecale Wittmack) is an artificial intergeneric hybrid between parent wheat (Triticum spp.) And rye (Secale spp.), what makes the history and evolution of triticale as a species so unique compared to other cereals like wheat or rye, is that its evolution occurred during the last 140 years and is almost completely directed by humans (Mergoum et al. 2009). The origin of triticale dates back to 1873 when the Scottish botanist A. S. Wilson made the first cross between wheat and rye.

Triticale breeding programs were started in Russia in the 1920s (GK Meister, V.E. Pisarev, and others), in Mexico (CIMMYT), Poland and France in the 1960s, as well as in Brazil, Portugal and Australia in the 1970s (Oettler 2005; McGoverin et al. 2011). Triticale breeding is still not complete. Triticale breeding is still evolving, Wurschüm et al. (2017) evaluated the potential of genomic prediction for triticale breeding. Today, breeders are extremely interested in the application of modern technologies, e.g. doubled haploid breeding, embryo rescue, genomic assisted breeding, etc., for an efficient and targeted triticale breeding. The production of doubled haploids provides a solution for accelerating the breeding process [12].

New crop has aroused great interest in the world. It gives 1.5-2 times more yield than wheat, unpretentious in cultivation, resistant to diseases, drought and frost. But what is the main advantage of triticale and flour made from it for the baking industry? Compared to wheat grain, protein of triticale grain is richer in essential amino acids such as lysine, threonine and leucine. Triticale starch contains less amylose than rye and wheat starch, which makes its digestibility easier for people:

TABLE I. PROXIMATE COMPOSITION OF TRITICALE, WHEAT AND RYE (DRY BASIS)

Cereal	Protein (%)	Starch (%)	Crude fibre (%)	Ether extract (%)	Free sugars (%)	Ash (%)
Spring triticale	10.3-15.6	57-65	3.1-4.5	1.5-2.4	3.7-5.2	1.4-2.0
Winter triticale	10.2-13.5	53-63	2.3-3.0	1.1-1.9	4.3-7.6	1.8-2.9
Spring wheat	9.3-16.8	61-66	2.8-3.9	1.9-2.2	2.6-3.0	1.3-2.0
Winter wheat	11.0-12.8	58-62	3.0-3.1	1.6-1.7	2.6-3.3	1.7-1.8
Spring rye	13.0-14.3	54.5	2.6	1.8	5.0	2.1

a. Origin: FAO [5].

A large territory of Russia with its natural and climatic conditions is a promising region for the cultivation of triticale crops for eating. The most favorable placement of the main sown areas of triticale (229 thousand hectares) within the subboreal belt on the soil provinces of the lowland territories of Russia with the possibility of expansion to the north.

According to our estimates, today Russia can produce such an amount of triticale food, which can provide more than 300 million people, that is 2 times more than the country's population [3]. Obviously, the production of such quantity of agricultural products is a significant export potential of the country, which requires not only high technological level of production, but also a modern state system for monitoring the state and forecasting crop yields of triticale to make necessary management decisions.

The aim of the study is to describe the adaptation methodology of the crop growth monitoring system (CGMS) used in the European Union, in Russia, to predict the yield of triticale crop.

II. Research results

The CGMS system consists of the WOFOST biophysical model, a database that includes meteorological, agrometeorological, statistical, soil geographic data and a statistical model of yield forecasts. All its components are combined into several independent modules (Fig. 1). This specification contains input data that can be used as a stand-alone product for further analysis. Taking into account the fact that this system uses a structured database, it has been adapted in many countries of the world to monitor the state of agricultural crops [8].

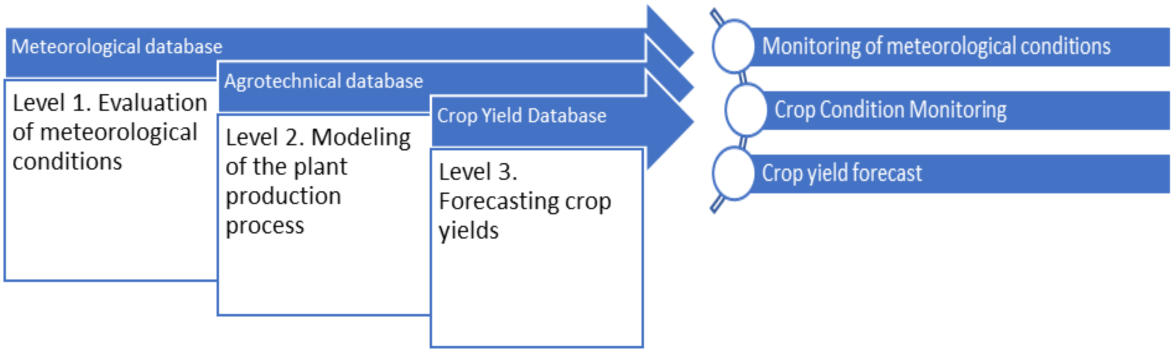

Fig. 1. The general scheme of the CGMS system

The plant growth monitoring system (CGMS) was adapted by us for beginning in region of Russia.

The initial data for forecasting is information about the acreage, crop yield, cultivation region and other data. In our calculations, we focused on the data of Rosstat (2017). The triticale sowing area in Russia consists of 102.9 thousand hectares [11], localized in 20 regions of the Russian Federation, mainly located in the easten of the European part of Russia in the basin of the Volga River and its tributaries (Fig. 2).

Soil provinces of the flatlands of Russia: Oksko-Don; Nizhnekamsk; South Russian; Zavolzhskaya; Don; Syrtov-Zavolzhskaya

Fig. 2. Localization of the main acreage of triticale within the subboreal belt

The climate in this territory of Russia is continental with hot summers and cold winters. Winter temperatures range from –11 ° C in the west to –20 ° C in the Urals, and summer temperatures vary from + 17 ° C to + 20 ° C. The distribution of precipitation over the territory is also uneven. The central part of the region is more moist (500–600 mm per year). The lack of precipitation is in the south of the region.

Carrying out the relevant stages of the adaptation of the CGMS system improves the accuracy of the characteristics of the development of triticale crops during the growing season and consists of the following steps:

- creation of a database of meteorological and phenological data available for the study area. The database should include observations for the past 15 years;
- creation of a database of soil characteristics of the researching;
- calibration of the agrometeorological model WOFOST;
- creation of a database of crop yields in the scale of administrative units available in local statistical organizations;
- adaptation of the scheme for forecasting the yield of a crop in the context of administrative units;
- technological adaptation of software for the calculation system.

The CGMS-Russia/20 system is used a statistical model for predicting the yield of triticale in the context of 20 administrative units of Russia located in the researching square of the subboreal belt in the soil provinces of the lowlands (Fig. 2). For this purpose, is used the approach in the research[14], in which the results of biophysical modeling of crop growth serve as predictors. These results are an integral characteristic of crop development depending on meteorological conditions and soil characteristics. In this case, the final yield can be written as:

$$Y_T = b_0 + f(T) + f(simulation) + e, \quad (1)$$

where $f(simulation)$ is a function describing the contribution of the results of biophysical modeling of crop growth depending on weather conditions in the overall yield, t/ha;

f(T) - yield trend over the observed period, t/ha;

e - random deviation not related to the trend, t/ha;

b_0 is the yield value excluding meteorological factors and trend, t/ha.

Following the logic of the authors of [15], equation (1) can be rewritten as:

$$Y_T = b_0 + b_1 T + b_2 S_T\ , \quad (2)$$

where Y_T and S_T are the estimated yield and predictors resulting from biophysical modeling, t/ha;

T, b_0, b_1 and b_2 are regression coefficients;

b_0 is a constant representing the average official statistical yield, t/ha;

b_1 is the value calculated from the equation of the trend of yield, t/ha;

b_2 is a constant describing the contribution of meteorological conditions and varying from 0 to 1.

It is proposed to adapt the CGMS-Russia/20 system for forecasting triticale yields in stages:

1) the selection of optimal predictors for predicting the yield of triticale using a regression model;

2) a comparative analysis of the accuracy of the forecast yield of triticale using a regression model with actual data.

In the first step, the bioproductivity parameters of crops are total dry biomass, biomass of productive plant organs, leaf surface area index, which can be determined for two types of calculations - for sufficient and insufficient moisture.

To determine the most informative predictor, the least squares method is used, which determines the minimum difference between the predicted and actual yield.

Studies have shown that the smallest quadratic error was observed when using as predictors of leaf surface area index with insufficient moisture (WLAI) and dry biomass of productive organs in conditions of insufficient moisture (WLYS). The first predictor (WLAI) is more informative in the initial phase of development - before the formation of productive organs, and the other predictor (WLYS) - at a later date, after the beginning of the formation of productive organs [16].

At the second step, using the above-selected predictor, the prediction accuracy of triticale was estimated for each administrative unit of the studied region of Russia. The following statistical characteristics were used for the evaluation:

a) relative forecast error:

$$APE = \frac{|Y_f - Y_T|}{Y_T} \times 100, \quad (3)$$

where Y_f is the actual yield, t/ha;

b) error variance:

$$RMSE = \sqrt{\frac{(Y_f - Y_T)^2}{N}}, \quad (4)$$

where N is the number of points;

c) the average deviation between the actual and prognostic values of yield:

$$RES = \frac{(Y_f - Y_T)}{N}, \quad (5)$$

The relative error in forecasting the yield of triticale, made in the second decade of June 2017 [11], in administrative regions of the studied region of cultivation of this crop in Russia, varies within fairly large limits, however, it does not exceed 10% (Table 2). The average relative error is 10%. In absolute values, the mean square error of the forecast was 0.31 centners per hectare, which is within the permissible limits of the prediction accuracy determined for the CGMS-Europe system.

TABLE II. EVALUATION OF THE ACCURACY OF THE FORECAST YIELD OF TRITICALE IN THE ADMINISTRATIVE REGIONS OF RUSSIA IN 2017

Administrative region	**Actual yield, c/ha**	**Expected yield, c/ha**	**Relative error of the forecast,%**
Republic of Bashkortostan	22.6	30.6	35
Kirov region	19.2	19.0	1
Mari El Republic	14.4	14.5	1
The Republic of Mordovia	52.0	50.5	3
Nizhny Novgorod Region	19.5	20.2	4
Orenburg region	18.0	28.6	58
Saratov region	26.7	30.3	13
Penza region	31.3	32.0	2
Perm region	10.9	9.8	10
Samara Region	30.7	28.7	7
Udmurtia	22.8	19.0	17
Republic of Tatarstan	34.3	35.9	5
Ulyanovsk region	16.5	17.2	4
Chuvash Republic	29.3	34.5	18
Volgograd region	21.9	22.0	1
Belgorod region	54.4	58.3	7
Rostov region	27.1	26.3	3
Voronezh region	31.5	33.1	5
Bryansk region	40.0	39.1	2
Kursk region	59.7	60.3	1

The lowest yield of triticale was predicted in the Perm region (9.8 centners per hectare) and the Republic of Mari El (14.5 centners per hectare). The actual yield in these regions was 10.9 and 14.4 c/ha.

The highest yields were predicted in the Kursk, Belgorod regions and the Republic of Mordovia and were, respectively, 60.3 c/ha, 58.3 c/ha and 50.5 c/ha, the actual yield in these areas was 59.7 c/ha, 54.4 c/ha and 52.0 c/ha.

Thus, the regression method for predicting the yield of triticale, where the parameters of crop productivity were used as predictors, allowed us to obtain satisfactory values of the average regional yield.

Technological adaptation of the CGMS system was to modify and compile the source code of the program, written in the C ++ programming language, by the Microsoft Visual C ++ 6.0 compiler in the Windows 7 environment, including the statistical data processing unit for yield prediction using functions such as linear regression and scenario analysis.

III. CONCLUSION

Thus, using the CGMS system, predictions of crop yields for triticale were made for the regions of Russia, taking into account the climatic, biological and agrotechnical features of cultivation.

In conclusion of prediction of triticale yield could provide an example on how model simulations can be carried out to evaluate the impact of climate change and potential adaptation strategies. This study has been work on finding out whether indicators from CGMS can be used in a regression model to explain year to year variation of triticale yield in Russia province during the growing season and before harvest. The strategies for each model were identified and compared in order to evaluate the appropriate model for this research. The CGMS Statistical Tool was found more efficient to satisfy the objective of this research. The predictors of CGMS-Russia/20 performed best at regional level to explain year to year variation.

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