CALIBRATION AND PARAMETERISATION OF THE AQUACROP MODEL FOR GROWING WINTER WHEAT IN BULGARIA

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Abstract

The sustainable development of modern agriculture and the manufacturing of quality crop production requires a precise assessment and management of the conditions and potential of the available resources. The use of numerical models in operational practice gives insight into the effective utilization of water resources. Numerical modeling methods can be used to assess of the extent and negative impact of agrometeorological drought. It is an increasingly common phenomenon and affects the quantity and quality of the harvest. The AquaCrop model is suitable for estimating the growth and productivity of agricultural crops in areas with insufficient moisture.

Our research aims to calibrate and optimize the parameters of the AquaCrop model for winter wheat under the conditions of the country. This will be achieved through conducting a field experiment. The collection of observed and measured data will enable their comparison with the results of the model simulation.

Through the AquaCrop model, water effectivity and yield sensitivity to available water reserves will be estimated. In the process of parameterization of the model, the values of the elements of the meteorological, biological, and soil block of the model affecting the soil water balance and natural fertility will be optimized.

The obtained results will be widely used in the compilation of agrometeorological forecasts and determination dates for the onset of drought in different regions of the country.

Keywords: *winter wheat, calibration, AquaCrop, parameterization, field experiment, yield simulation*

1. INTRODUCTION

Agricultural lands in Bulgaria are located in an area with insufficient moisture (Georgieva et al., 2022, Kazandjiev V., V. Georgieva, 2020, Kazandjiev, V et al., 2020, Kazandjiev, V et al., 2019, Kazandjiev, V et al., 2017). The research of soil moisture reserves shows that very often, especially in the last 20 years (V. Georgieva, 2013), the reproductive phase of crops passes with soil and atmospheric drought, which reduces yields from agricultural crops in many regions of the country (Kouzmova D ., et al., 2020).

Wheat in Bulgaria, is grown under non-irrigated conditions. One of the reasons for this is the amount of irrigated areas, which for the country is slightly more than 3% of the cultivated areas (FAO).

Future climate studies show that trends in uneven distribution of precipitation and prolonged droughts in both autumn and spring will be frequent (Kazandjiev et al., 2022, Trnka M. et al., 2015, Charampopoulus I., 2016, Georgieva V., et al., 2017). Winter wheat production will become increasingly risky in areas of the country that are traditional producers of this crop. Therefore, the assessment of risk in real time, the forecast of the development and productivity of the main crops under the specific conditions is key, given the increasingly widespread penetration of digitalization in agriculture.

The development of numerical models in recent decades has created opportunities to improve our understanding of crop behavior, their physiology and their responses to environmental changes (Steduto et al., 2009). In this way, they are tools for assessing the environmental conditions, its influence on the development and productivity of crops, forecasting and making agrotechnical decisions.

Numerical models have been used in operational agrometeorological practice for decades (Kazandjiev V., V. Georgieva, 2006, Chervenkov H., et al., 2017). The application of numerical models in practice requires knowledge of the specifics of the model and preliminary processes of adaptation to local conditions. After analyzing the advantages and disadvantages of the most widely used models, the AquaCrop model was chosen as suitable for the conditions of Bulgaria. This model is recommended for use in areas with insufficient moisture, such as the agricultural areas of the country (Steduto P., et al., 2009). An advantage of this model is the possibility of evaluating water productivity under different conditions - irrigated and non-irrigated. AquaCrop is a relatively new model recently developed by FAO to provide an easy-to-use modeling tool for a wide range of users - farmers, agricultural consultants, water managers and policy makers. The model focuses on water income as the most limiting factor of crop growth, especially in arid and semi-arid regions where water stress varies in intensity, duration and time of occurrence. AquaCrop has a simple, user-friendly structure parameters that can be easily monitored in the field; for example, percent plant cover instead of leaf area index (LAI) and other biomass-related physiological inputs; numerical or descriptive characterization of crop tolerance to water stress, soil mechanical composition and nutrients. The relatively simple structure and reduced number of parameters can facilitate the calibration and use of the model for different crops and under different management strategies. Despite the reduction and simplification of input variables, the model supports a significant number of basic inputs, biomass and soil water components throughout the growing cycle and the final crop yield (Steduto et al., 2012).

Calibration is an important part of the modeling process, as it enables numerical results to be obtained from the model and their reliable use in applications. Essentially, model calibration involves adjusting the model parameters to reduce the error between the model output and the measured data; statistical procedures for mass flow optimization; correcting model parameters with directly measured values; "tuning" a set of model parameters that may not be directly measurable using overall model performance and understanding model sensitivity.

Our research aims to calibrate and optimize the parameters of the AquaCrop model for winter wheat under rainfed conditions of the country. In the study will test the ability of the AquaCrop model to simulate canopy cover (CC), total soil water content (TWC), biomass (B) and yield of wheat under the conditions of Bulgaria. In the study, we will use the data from a field experiment conducted in 2010/2011 in Lozenets, Dobrich with coordinates 43°46’44’’; 27°44’30’’ and elevation 210 m a.s.l.

2. MATERIAL AND METHODS

2.1. Description of location and data

The field experiment for calibration was carried out in the region of the North-eastern Bulgaria where the production of the wheat in Bulgaria is concentrated. The region is located in the Temperate-Continental climate subregion of the European-Continental climate region. This sub-region is characterized with the continental climate - cold winter and hot summer. Precipitation is maximum in summer and minimum in winter. The experimental area is located in the Eastern climatic region of the Danube Plain, where the continental character is the most moderated, compared to the other regions of the Temperate-Continental climatic sub-region. The area is 210 m above sea level. The studied area is characterized by Haplic and Typical Chernozem. The sowing date is in the period 1-4 October 2010. The observations were made on the winter wheat variety Enola growing at rainfed conditions.

Table 1. Some Agroclimatic Characteristics of the region:

Stations	Date of the transition of air temperature above 5°C in the spring	Date of the transition of air temperature below 5°C in the autumn	Tsum (°C) during the vegetation season	R sum [mm] during the vegetation season	ETo (mm) III-X
G.Toshevo	27.II	28.XI	4115	371.5	867
Krushari	24.II	27.XI	4121	372.8	845.3

The AquaCrop model considers the state of the soil-plant-atmosphere system in the context of conditions for crop growth, development and productivity. The model was created to estimate water productivity. Includes two panels - environment and simulation. The environmental panel includes soil with water balance, crop with crop development, growth and yield processes, atmosphere – thermal regime, rainfall, ETo and Carbon dioxide concentration, field and irrigation management, (Steduto P. et al., 2009). In the simulation panel simulation period and initial conditions are specified. It is possible to use some parameters from the reference manual for AquaCrop as default (Raes et al., 2012).

The climate component of the model is described with 5 input meteorological parameters: daily minimum and maximum air temperature, daily rainfall, daily ETo and mean annual carbon dioxide concentration in the atmosphere. Daily values of ETo are calculated according to the Penman-Monteit by using the software CropWat 8. The crop system consists of five components – phenology, green canopy cover, rooting depth, biomass production and yield. From field experiment we used phenology, canopy cover, biomass and yield. For rooting depth we are using the information about the time of maximum rooting depth from literature (Georgieva Ya., 1963).

AquaCrop uses information about canopy development, not for LAI. We used data from field observation during the main phenological stages – tillering, stem elongation and anthesis.

2.2. Used Data

Daily data for main meteorological elements were used, Table 2. The crop non-conservative data was collected from field experiment carried out in village Lozenets, Dobrich DC. For this purpose, the following observations and measurements will be made, Table 2:

Table 2. Measured meteorological and agrometeorological elements.

Measurement	**Method of measure**	**Conditions of measurement**
1. Air temperature	Observations in synoptic and climatic stations of observational network of NIMH.	°C/ 2 m
2. Relative Air Humidity	Observations in synoptic and climatic stations of observational network of NIMH.	%/2 m
3. Wind speed	Observations in synoptic and climatic stations of observational network of NIMH.	m/s 10 m
4. Rainfall	Observations in synoptic and climatic stations of observational network of NIMH.	mm / 2 m

5. Sunshine duration	Observations in synoptic and climatic stations of observational network of NIMH.	h/2 m
6. Soil moisture content	Gravimetric method	10, 20, 30, 40, 50, 60, 70, 80, 90, 100 cm,
7. Date of occurrence of the main phenological stages	Observations in agrometeorological stations of observational network of NIMH.	%
8. Crops Density	N/m2 or N plants on 10 m in two next rows	number
9. Canopy cower (CC)	Data from field experiment	%
10. Biomass	Data from field experiment	t/ha
11. Yield	Data from field experiment	t/ha

2.3. Non-conservative crop characteristics

The experiment was realized on the winter wheat, cultivated at rainfed conditions.

Phenological development:

Phenological stage	Sowing	Emergence	Tillering	Stem elongation	Heading/ Antesis	Flowering	Maturity
Date of occurrence	1-3 X	12 -15 X	20 III-10 IV	11 IV-25.V	25-29 V	2-4 VI	6-8 VII

Soil water characteristics:

Soil layer (cm)	Permanent wilting point (m^3/m^3)	Field capacity (m^3/m^3)	Saturation (m^3/m^3)	Bulk density (g/cm^{-1})
0-20	15.7	35.6	44	1.2
30-50	17.4	34	43	1.3
60-100	16.6	31.5	46	1.3

Soil water reserve for tree soil layers – 0-20 cm, 0-50 cm and 0-100 cm was measured each decade. The minimum of information for simulation of crop growth, yield and water productivity are available (Steduto P., et al., 2012).

2.4. Methods

Version 7.0 of the AquaCrop - FAO, CropWat - FAO model was used to calculate evapotranspiration, as well as Statgraphics statistical software for statistical evaluations of the relationship between the measured and simulated values of the studied indicators.

Measured and modeled data were compared statistically for assessing the model reliability. We use following statistical characteristics:

$$ME = \frac{1}{N}\sum_{k=1}^{N}(Modeled_k - Measured_k)$$

$$SD = \sqrt{\frac{1}{N}\sum_{k=1}^{N}\left(Modeled_k - Measured_k - ME\right)^2}$$

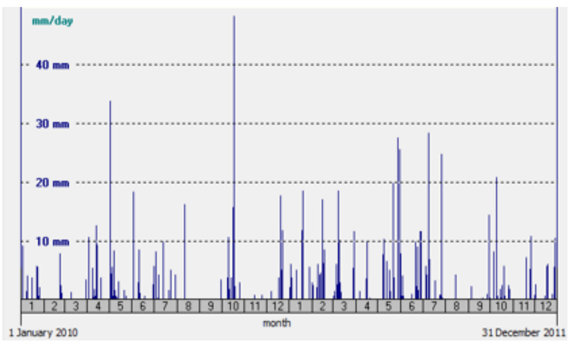
$$CC = \frac{\sum_{k=1}^{N}\left(Modeled_k - \overline{Modeled}\right)\left(Measured_k - \overline{Maesured}\right)}{\sqrt{\sum_{k=1}^{N}\left(Modeled_k - \overline{Modeled}\right)^2 \sum_{1}^{N}\left(Measured_k - \overline{Measured}\right)^2}}$$

$$RMSD = \sqrt{\frac{1}{N}\sum_{k=1}^{N}\left(Modeled_k - Measured_k\right)^2}$$

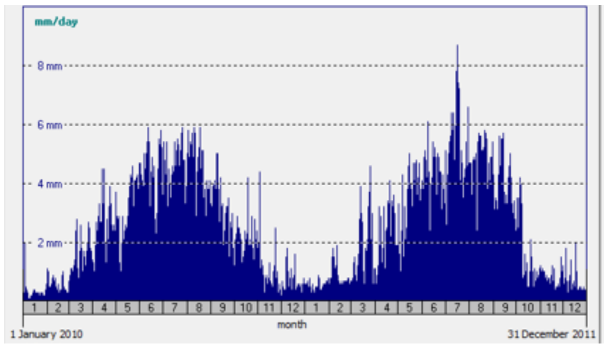
3. RESULTS

3.1. Parametrization

For simulation we use the data from two years, 2010-2011. The dynamic of the meteorological data are presented on figure 1.



a)



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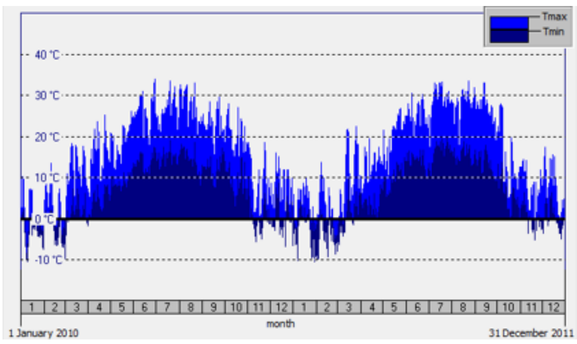

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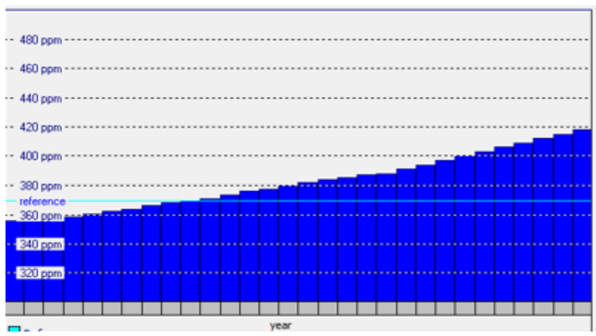

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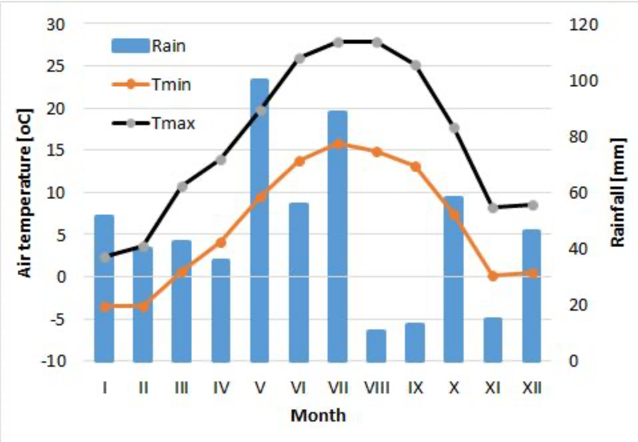


e)

Fig. 1. Dynamics of modelled: a) daily rainfall; b) daily evapotranspiration; c) daily min and max temperatures; d) concentration of CO2, and e) measured rainfall and tmin and tmax

3.2. Soil moisture

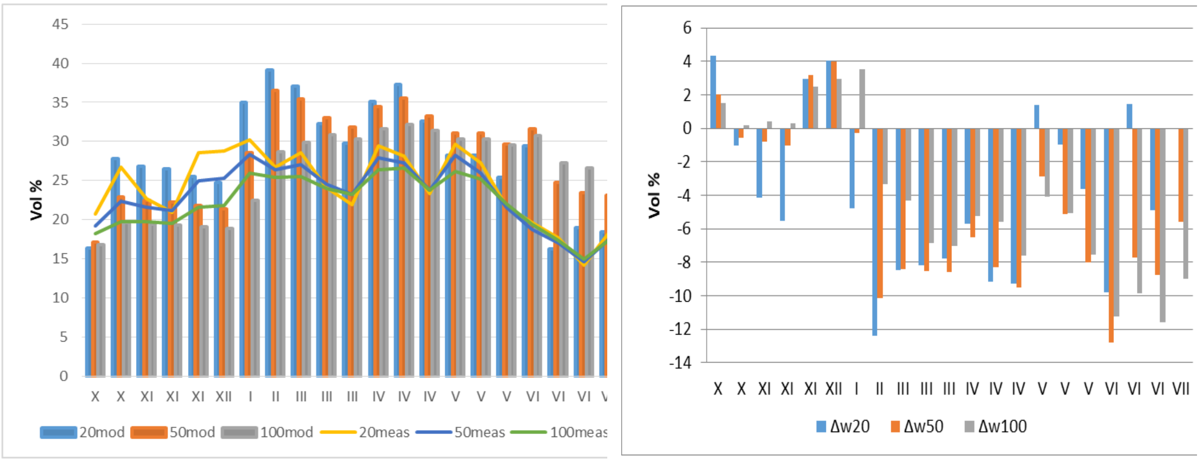
The soil water content was measured every ten days during the vegetation season and once of month during the winter, Table 3.

Table 3. Values of measured soil water content by layers and dates of measurement

Month	Date	Measured water content In different layers [mm]										
		Depth [cm]										
		5	10	20	30	40	50	60	70	80	90	100
X	7.10	23.9	20.4	17.9	17.05	18	18.1	18	17.4	17.0	16.4	16.3
	17.10	29.0	26	25.2	19.0	17.0	17.8	17.1	16.7	16.6	16.5	16.5
XI	8.11	21.5	23.2	23.4	23.5	19.7	18.5	18.4	18.3	17.1	17.3	16.7
	17.11	19.2	21.4	22.2	22.7	22.5	19.3	17.8	17.6	17.7	17.4	17.4
	27.11	30.4	27.4	27.8	24	21.4	18.7	18	17.9	17.8	17.4	16.6
	16.12	29.8	29.2	27.3	26	21.8	18	17.9	17.5	17.6	17.2	17.5
	17.01	32.4	29.6	28.6	27.4	25.4	26.6	25.9	25.5	24.8	22.8	17
	17.02	26.8	26.4	27	26.2	25.6	26.2	25.3	24.8	24.4	23.6	23.1
III	7.03	30	28.6	27.1	25.9	25.4	25.5	24.7	23.9	24.5	23	22.3
	17.03	23.4	23.8	25	24.8	24.8	25.6	25	24.7	24.0	22.8	20.5
	27.03	19.7	22.5	23.6	23.2	24.8	25.6	24.8	24.1	23.1	22.7	21.9
IV	7.04	30.3	29.3	28.6	26.2	26	27.4	26.7	25.1	24.2	23.8	23
	17.04	27.2	28.0	29.1	27.6	24.8	27.1	26.7	25.7	25.6	26.1	24.7
	27.04	22.3	24.2	23.6	23.4	23.2	25.7	25.2	24.4	24.1	23.4	22.4
V	9.05	30.6	30.2	28.1	26.2	26.8	27.3	25.7	24.9	23.8	22.9	21.9
	17.05	28.8	27.6	25.5	24.4	24.1	25.4	25.5	25.3	24.6	24	22.6
	27.05	21.3	21.4	22.6	21	20.5	23	23.4	23.4	22.8	21.6	21.2

VI	7.06	22.1	19.4	17.4	17	16.8	20.3	20.6	20.2	19.8	20	20.4
	17.06	18.5	17.7	16.8	16	15.9	17.5	18.1	17.8	17.6	17.6	18
	27.06	12.2	15	15.3	14.8	15.1	15.6	15.7	15.2	15.1	15.5	15.4
VII	7.07	21.5	17.4	16.5	16.6	16.2	17.1	16.7	17.2	17.4	17.8	17.9
	17.07	17.8	16.6	16.2	16.2	15.9	16.4	17.4	17.4	17.6	17.9	18.4
	27.07	24.4	22.2	17.8	16.3	16	17.1	17.5	17	17.4	17	17.6

The results from comparison between measured and modeled data show that during the autumn the measured data are underestimated. After February the modeled data exceeds the measured.



a) b)

Fig. 2. Measured and modelled a) - values of soil water content for three layers 0-20, 0-50 and 0-100 cm and b) - difference between them

In Table 4 are presented the statistical values of the comparison between observed and simulated soil water reserves by layers. The results confirm the above mention conclusions. The values of mean error and standard deviation show large deviations. In the same time the correlation coefficient for first and second layers is good.

Table 4. Statistical characteristics of simulated and observed soil water reserves

Soil Layers [cm]	ME	SD	CC	RMSD
0-20	0.58	0.72	0.76	0.24
0-50	0.55	0.64	0.71	0.26
0-100	0.55	0.63	0.58	0.32

3.3. Yields and Biomass

Using the data on the measured values of the meteorological and agro-meteorological elements and indicators and the soil characteristics that determine their hydro-physical properties, we made a series of simulations, Figure 3.

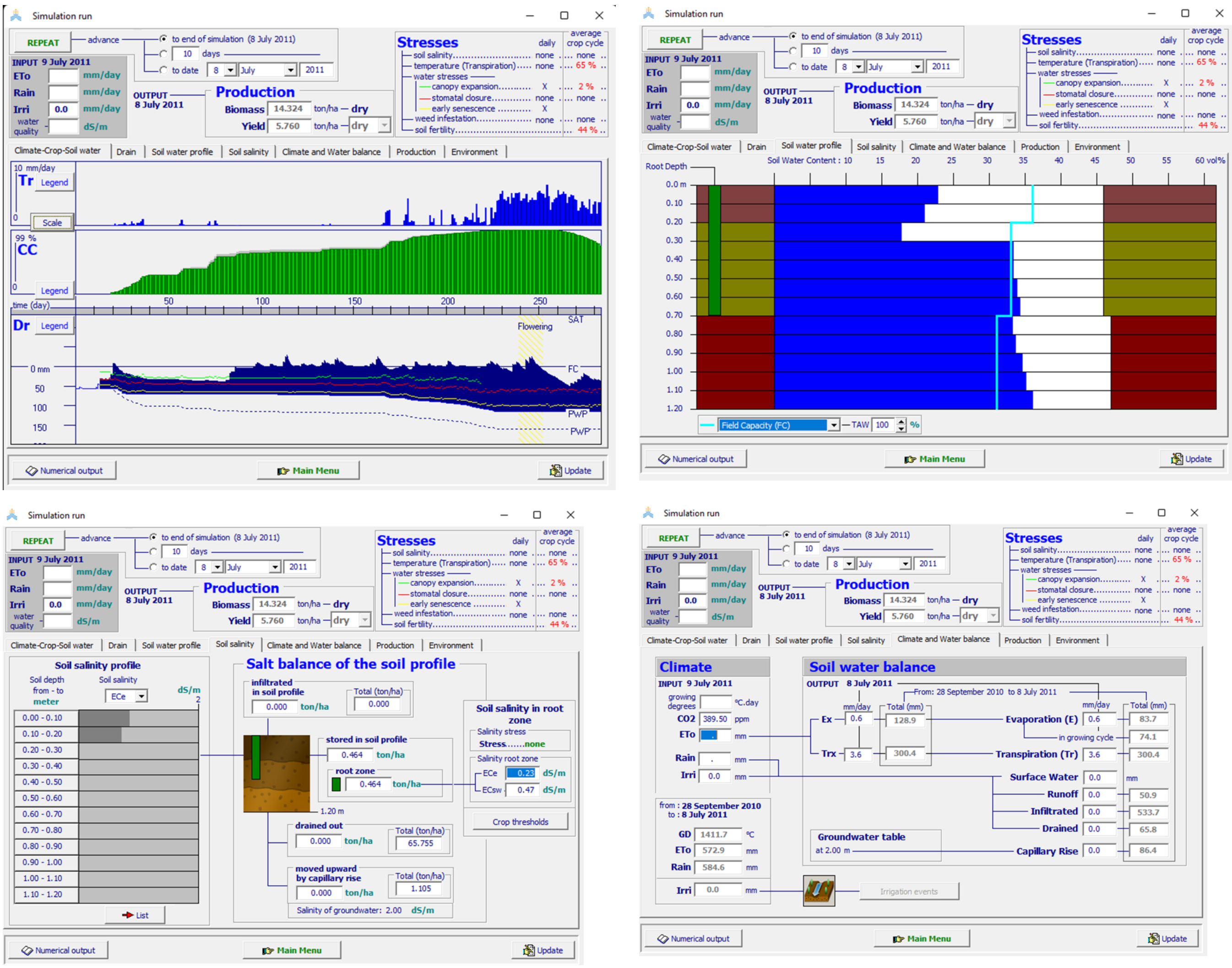


Fig. 3. The results from simulation after run of AquaCrop

They show the dynamics of daily temperatures, the accumulated temperature sum, the time distribution of soil moisture within the hydrological constants and by layers, as well as the conditions of occurrence of water stress. All these indicators condition certain (acceptable from the point of view of the conducted field experiment) quantities of aboveground biomass and yield.

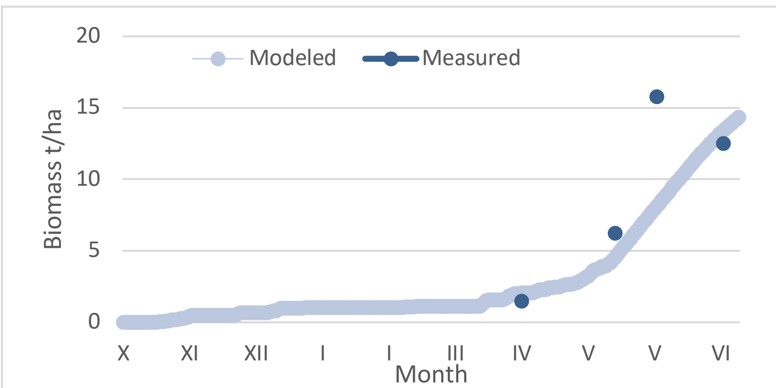


Fig. 4. Dynamic of the modeled and simulated biomass (t/ha).

The simulated dry biomass values for stem elongation and flowering exceeds the modeled values. At the tillering and the end of the vegetation season - at maturity the modeled and measured values close, fig. 4.

The measured yield in the field experiment was determined by averaging the results of 36 test plots and corresponds to 4.32 t/ha. The difference between measured and simulated yield is 1.44 t/ha or 33.34% higher than the real value. This proves the need for even more precise calibration of the model`s water and biological block parameters.

4. DISCUSSION

The AquaCrop model was developed to simulate growth processes in a temperate climate [50]. This study aims to present our results of the process of calibrating and validating the AquaCrop model for winter wheat (Triticum aestivum L.) in Bulgarian conditions using version 7.0 of the model.

The results showed that the AquaCrop model (v 7.0) is able to simulate perennial growth of winter wheat (Triticum aestivum L.) under normal, dry and wet seasons in Bulgaria. The experience of this numerical experiment may allow many future applications for other types of crops and other regions of the country. It is also possible to use this model to simulate the growth of pasture grasses, which are of great importance for pasture livestock management. The capacity of the AquaCrop model allows the simulation of the effect of forced dormancy in temperate winter cereals, as well as the effect of agrometeorological conditions and soil on leaf area and biomass growth, which will continue to be investigated.

The model describes growth, development and productivity and represents well the growth from sowing to harvest maturity, as well as soil moisture conditions, periods of heat and water stress in winter wheat.

AquaCrop does not account well enough for the phases of phenological development and the extent of this dependence on hydro-thermal conditions. This explains the underestimation of the estimates of their simulated values. The potential growth rate of the leaf surface is proportional to the product of the seeding density, the number of leaves of the selected variety and depends on the size of the leaf.

The AquaCrop model simulates biomass growth with reasonable accuracy under natural atmospheric and soil moisture conditions. Experiments are to be conducted to predict growth, development and productivity under irrigated conditions. The full range of irrigation practices to compensate for the lack of rainfall, allowing the model to quantify the results with reasonable accuracy.

Drought greatly reduces the development, growth and yields of winter wheat crops, which greatly affects the economic indicators of grain production. To increase the accuracy of the model, the effect of drought on the growth and development of crop productivity must be taken into account. Detailed simulation should also be linked to crop phenological development. Variations in the growth of cereals must take into account in detail the conditions of moisture - natural or through irrigation.

This assessment provided confidence in the model's ability to adequately simulate the hydrothermal conditions of winter wheat growth and development and expected yields. The importance of soil moisture deficit for winter wheat resistance has also been demonstrated through the application of other similar models. We found that AquaCrop can estimate soil moisture with acceptable accuracy. Soil water content was reasonably simulated, although simulated values tended to be more variable than observed values. Most winter wheat varieties are moderately to poorly adapted to low soil moisture availability. Lack of water restricts the growth of stems and leaves, which in turn causes a lower yield. Future studies should investigate the sensitivity of our results to a much wider range of soil profile and available water.

5. CONCLUSIONS

The results obtained in this study show that AquaCrop is suitable for simulating the growth of annual winter cereals under different water regimes;

Further experiments are needed to adjust the parameters developed in this study to account for other environmental conditions and correctly estimate total fresh and dry biomass at different periods of winter wheat development;

Future annual cereal modeling studies should continue to compare simulations of soil moisture content under different irrigation practices and climate conditions. In addition, the implementation of planned experiments with different types of autumn and spring crops to predict their productivity in the conditions of climate change and increasingly extreme conditions cannot always be overcome by breeding methods.

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