EEET ECOLOGICAL ENGINEERING
& ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2021, 22(5), 103–109
https://doi.org/10.12912/27197050/139312
ISSN 2719-7050, License CC-BY 4.0

Received: 2021.06.15
Accepted: 2021.07.10
Published: 2021.08.01

Modelling Irrigation Regimes of Different Varieties of Rice with AquaCrop Software

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ABSTRACT
The article presents the results of the application of modern information technologies, which allow agricultural producers to precisely control the dynamics of water consumption at the level of irrigation system, farmland and individual fields of rice crop rotations under the conditions of drip irrigation. The use of computer programs enables optimization of irrigation regimes and delivers savings in terms of water, energy, technical means and labor resources, contributing to an increase in yields and improvements of their quality, increases in economic efficiency and environmental safety of agriculture on irrigated lands. As a part of SRW "Development and improvement of irrigation regimes of rice and related crops of rice crop rotation on the basis of normalization of irrigation water and determination of the dynamics of evapotranspiration at the field level", AquaCrop software was used to model the productivity of rice under conditions of drip irrigation. The results of research on the topic of improvement of technological processes for growing modern varieties of rice in order to enhance seeding and harvesting properties, which were conducted in 2017 at the Institute of Rice NAAS, were used as experimental data. Indicator data, including temperature, wind speed and precipitation in 2017 were obtained from the local weather station, whereas information on the duration of the sunny day, local coordinates etc. was gleaned from Internet resources. AquaCrop models water and nutrient consumption to achieve desired yields and establish response to optimal and resource-saving irrigation of crops with different biological parameters, including rice. Components of the cultivation process of different rice varieties were established with simulation modeling. Convenience, accuracy and reliability of the developed model for management, modeling and decision-making from the perspective of yield formation of Vicont, Premium and Ukraine-96 rice varieties as well as development of irrigation regimes for effective agricultural production were demonstrated. Adaptation of the information provided by AquaCrop on studied rice varieties allowed automatic and sufficiently accurate generation of biologically optimal irrigation regimes for Vicont, Premium and Ukraine-96. Yields and water productivity of aforementioned rice varieties were also compared in the experiment, with the highest values for both parameters achieved by Vicont – 9.5 t/ha and 1.29 kg/m^3, respectively.

Keywords: AquaCrop software, technologies, rice, irrigation, yield, efficiency.

INTRODUCTION

Water scarcity is a common issue when it comes to achieving sustainable crop yields in the Southern Steppe of Ukraine, which is in the zone of inconsistent and insufficient natural water content. According to scientists, water scarcity affects more than 20% of the total area, which is also impacted by reduction in fresh water supplies (Vozhegova, 2014). In recent years, precipitation has increased by 33%. However, this was observed alongside with an increase in the sum of effective temperatures above 5°C by 673°C and the precipitation is characterized by uneven distribution during the vegetation season, and in dry summer months occurs in the form of heavy rains (Vozhegova, 2019). For these reasons, irrigation, which is based on biological characteristics of plants, zonal and local soil and climatic conditions, is a crucial component of technologies for growing crops. Increase in the size and quality of yields under conditions of reduced irrigation and lower irrigation rates is the main goal of innovative irrigation technologies both in Ukraine and globally (Averchev et al., 2017; Schwartau et al., 2019). The actual need for the irrigation water and patterns for its rational use can only be determined throughout the irrigation season by performing timely, short-term calculations of rates and timeframes, according to which irrigation should be conducted.

Nowadays, there are many models of crop productivity that allow assessing the effectiveness of the irrigation regime. Although simulation models of plant growth and development that can be created in DSSAT and CROPWAT software packages are practical, parameters such as soil fertility, its ecological and reclamation conditions cannot be controlled, and crop rotations cannot be optimized based on comprehensive analyses of additional data (Surendran et al., 2015). To solve these problems, scientists from the Department of Land and Water Resources of the FAO UN developed AquaCrop, a specialized software that models water and nutrient consumption to achieve desired yields and establish response to optimal and resource-saving irrigation of crops with different biological parameters, including rice (Raes et al., 2012; Vozhehova et al., 2019; Markovska 2019). Generated models have been successfully tested for many crops around the world, e. g. barley in the Southern Sahara in Africa, wheat in Iran and the western provinces of Canada, fodder crops in Ethiopia, corn for grain in California (USA). Many studies conducted in the arid regions also used AquaCrop to optimize grain yields and aboveground mass using water-saving or biologically optimal irrigation regimes. For instance, Farahani and Garcia-Vilau developed an irrigation regime for cotton in Syria and Spain, Salem, etc.; for winter wheat with water-saving irrigation in arid areas of Iran, Iraq, etc. and for wheat in different regions of Ethiopia (García-Vila M et al., 2009; Steduto et al., 2012; Araya et al., 2019). In Ukraine, the use of simulation models of crop productivity still remains limited.

MATERIALS AND METHODS

As a part of SRW "Development and improvement of irrigation regimes of rice and related crops of rice crop rotation on the basis of normalization of irrigation water and determination of the dynamics of evapotranspiration at the field level", a model of the productivity of rice was developed using modern information technologies. With the help of AquaCrop version 6.0, the adaptation (calibration) of characteristics of each of the studied rice varieties was performed and irrigation regimes for 2017 vegetation season were developed according to the methods provided by the system. In addition, obtained models for productivity, grain yield and amount of irrigation water used for each of the studied rice varieties were compared. The results of research on the topic of improvement of technological processes for growing modern varieties of rice in order to enhance seeding and harvesting properties, which were conducted in 2017 at the Institute of Rice NAAS, were used as experimental data. Indicator data, including temperature, wind speed and precipitation in 2017 were obtained from the local weather station, whereas information on the duration of the sunny day, local coordinates, etc. was gleaned from Internet resources. The reference evapotranspiration was calculated using Penman-Monteith method, which is integrated in CropWat software. The average annual CO_2 concentration was obtained from the AquaCrop database.

RESULTS AND DISCUSSION

Following the input of data, diagrams of precipitation dynamics (Fig. 1a), reference evapotranspiration (Fig. 1b), temperatures (Fig. 1c) and CO_2 concentration (Fig. 1d) are generated, allowing the user to visually analyze information about the climatic conditions of the study site.

Information on seeding rates, weight of 1000 grains, germination level, distance between rows and plants as well as the number of days of the vegetation season grouped by phases for each of the studied rice varieties were also entered. Following the input of these parameters, the program automatically calculated the standing density of plants and the initial size of the crop cover (CC).

For Vicont variety, the following data were entered: weight of 1000 grains – 31 g, germination level – 81%, row spacing – 0.13 m, seed spacing – 0.02 m, seeding rate – 246.2 g. Based on these parameters, the standing density was calculated to be 9000000 pcs./ha and the initial crop cover was calculated to be 0.90%. For Premium variety, the following data were entered: weight of 1000

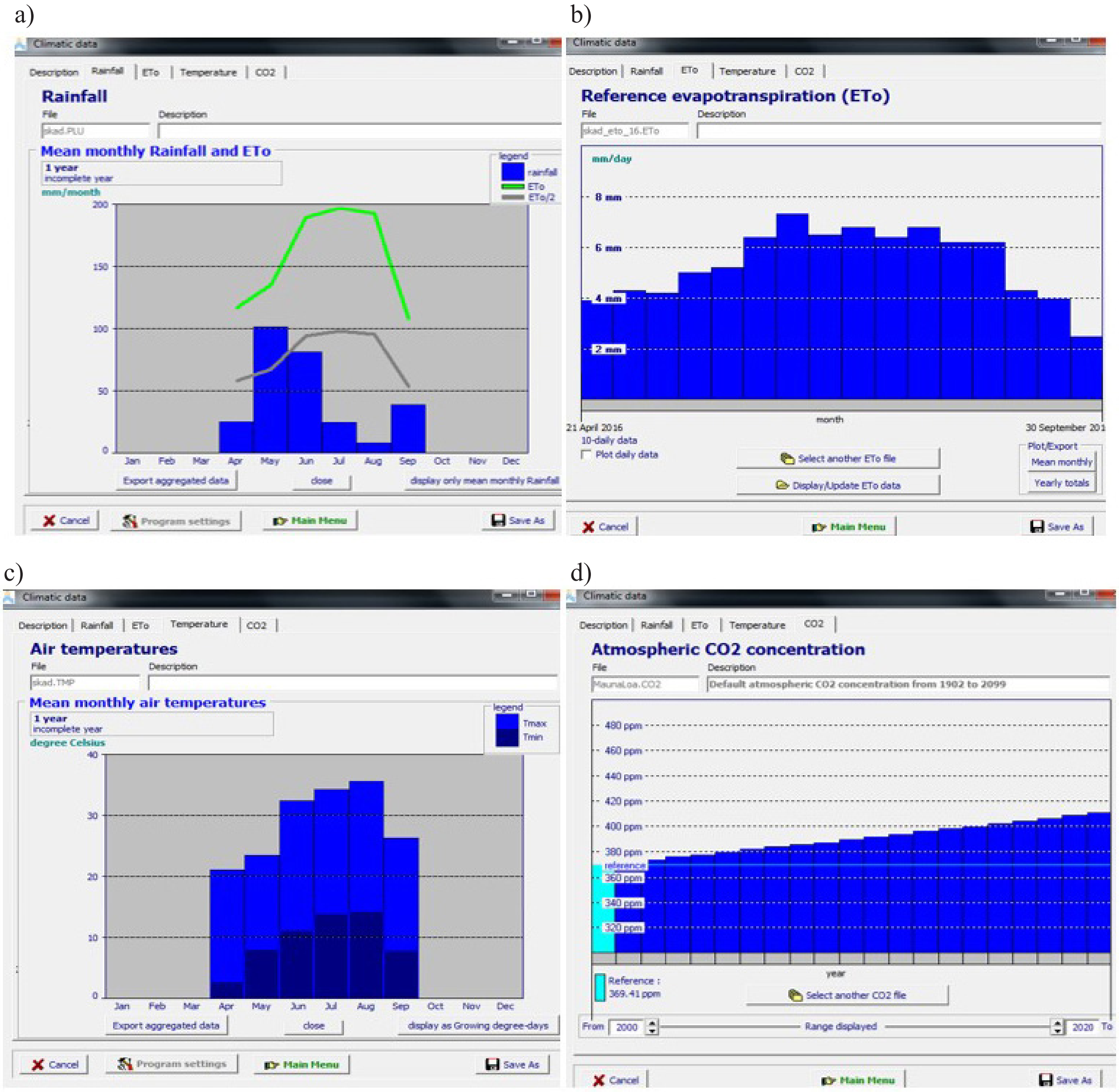

Figure 1. Precipitation dynamics (a), reference evapotranspiration (ETo) (b), maximum and minimum temperatures (c) and CO_2 concentration (d) at the study stie in 2017

grains – 30 g, germination level – 80%, row spacing – 0.13 m, seed spacing – 0.02 m, seeding rate – 236.5 g. Based on these parameters, the standing density was calculated to be 8879012 pcs./ha and the initial crop cover was calculated to be 0.89%. For Ukraine-96 variety, the following data were entered: weight of 1000 grains – 29 g, germination level – 76%, row spacing – 0.13 m, seed spacing – 0.02 m. Based on these parameters, the standing density was calculated to be 8550000 pcs./ha and the initial crop cover was calculated to be 0.86%.

The date of seeding in our study coincided with the start date of the modeling, i. e. the beginning of the vegetation season on April 30, 2017 for all varieties.

Next, we adapted the following parameters: the number of days from seeding to germination, to the date of formation of the maximum crop cover, to the date of "aging" CC and to the date of full maturity of the crop; as well as data on the duration of flowering of rice varieties. Required hydraulic characteristics of the soil from field observations (lowest field moisture content - FC), wilting moisture (WP) and compared to the texture of soil resources of the AquaCrop database according to the properties of local medium-loam soils at two soil levels (Fig. 2): for the soil layer 0.30 m FC was 22%, PWP 10%, for the layer 0.90 data FC 31%, PWP 15%.

After the calibration, an irrigation strategy was devised and the mode of "automatic generation of irrigation regimes", the method of drip

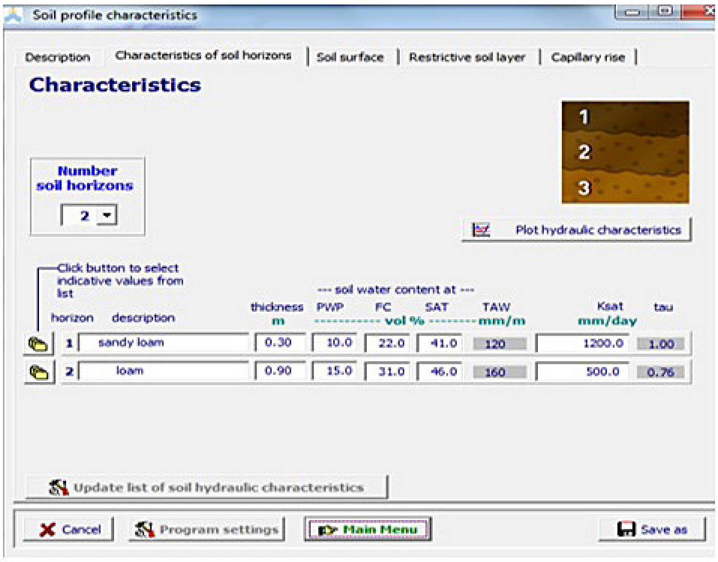

Figure 2. Features of "Soil profile characteristics" window

irrigation, criteria and depth were selected. Then, the scenarios modeling the existing irrigation schedule with different characteristics and options for the parameter of permissible depletion of the percentage of RAW were run. The main advantage of this mode of plotting is that the water content in the soil between FC (lowest field moisture content) and RAW threshold (water easily accessible to plants) is preserved, while water losses caused by deep infiltration are limited; water stress and crop losses are excluded, which is relevant for rice cultivation.

In our study, the strategy of creating a biologically optimal irrigation regime was chosen for a more convenient comparison of productive characteristics of rice varieties. After generating the diagrams "Climate-Culture-Soil Moisture" with features including the amount of biomass and grain yields, optimal ratios between the entered parameters of the irrigation regime and highest yields of rice varieties were analyzed. Figure 3a illustrates the dynamics of the simulated transpiration (Tr), crop cover (CC) and water content in the root zone (Dr) for Vicont variety during the 128-day growing season. Figure 3b, in turn, shows the consolidated water balance from all inflows and outflows. The schedule of the biologically optimal irrigation regime under conditions of 78% depletion of RAW with irrigation dates and fixed irrigation rate of 200 m^3/ha was developed and the total irrigation rate of 8600 m^3/ha was obtained. The yield of the Vicont variety was 9.5 t/ha (biomass 21.1 t/ha), with water productivity of 1.29 kg/m^3 and the ratio between the actual and potential biomass of 100%, considering the absence of stress during the period of crop cultivation (Fig. 3c).

Similar yield and irrigation modeling were performed for Premium and Ukraine-96 rice varieties.

Despite using the same irrigation rate of 8600 m^3 for all studied varieties, each had a different yield, amount of biomass and water

a) b) c)

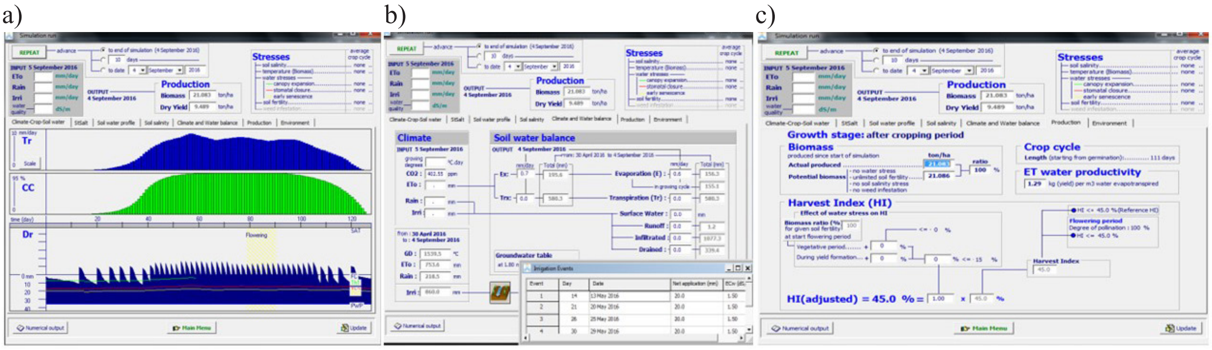

Figure 3. Generated forms for Vicont rice variety in the "Run modeling" mode

a) b)

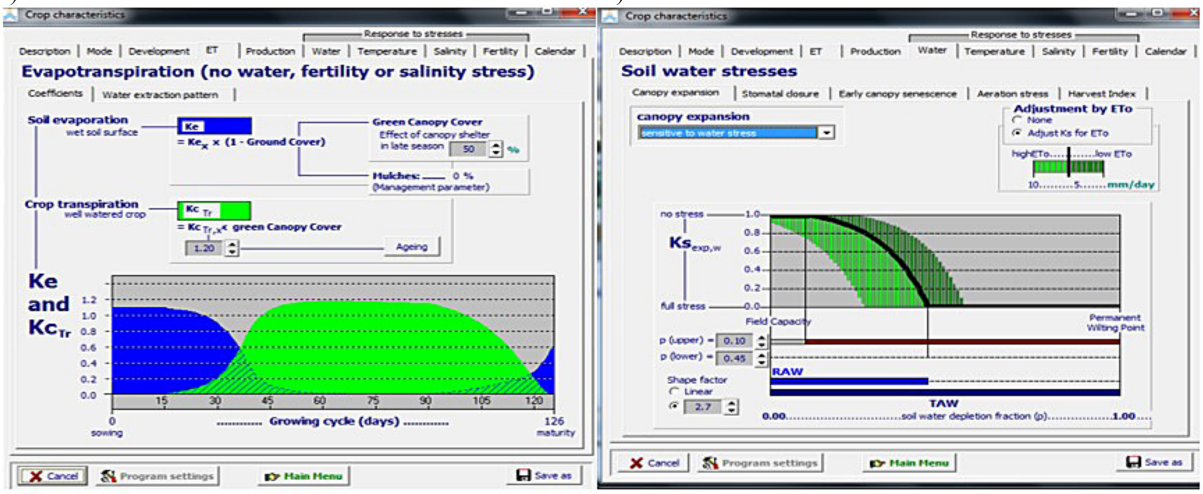

Figure 4. Features of "Crop characteristics" window

productivity. The yield of Premium was 9.2 t/ha (biomass 20.4 t/ha) and water productivity – 1.27 kg/m^3. The yield Ukraine-96 variety was 9.3 t/ha (biomass 20.7 t/ha) ha) with ETwp of 1.28 kg/m^3 and the ratio between the actual and potential biomass of 100%, considering the absence of stress during the period of crop cultivation. In "Characteristics" window, the user has the opportunity to adjust conservative parameters on the basis of climatic and agricultural conditions of a particular crop. Figure 4a shows evapotranspiration characteristics of rice, the crop coefficient Ks and the effect of crop cover in the last phase of the cycle. Figure 4b demonstrates the dynamics of water stresses with indicators of "increased crop cover", "closing of stomata", "premature aging of biomass", "aeration stress" and "dynamics of changes in the yield index during flowering and yield formation".

The ability to control water and salt balances, and all types of stress at certain stages of crop development is a major advantage of AquaCrop. Stress can be adjusted by increasing/reducing irrigation rates, or by changing the timing, plant density, etc. (Fig. 5).

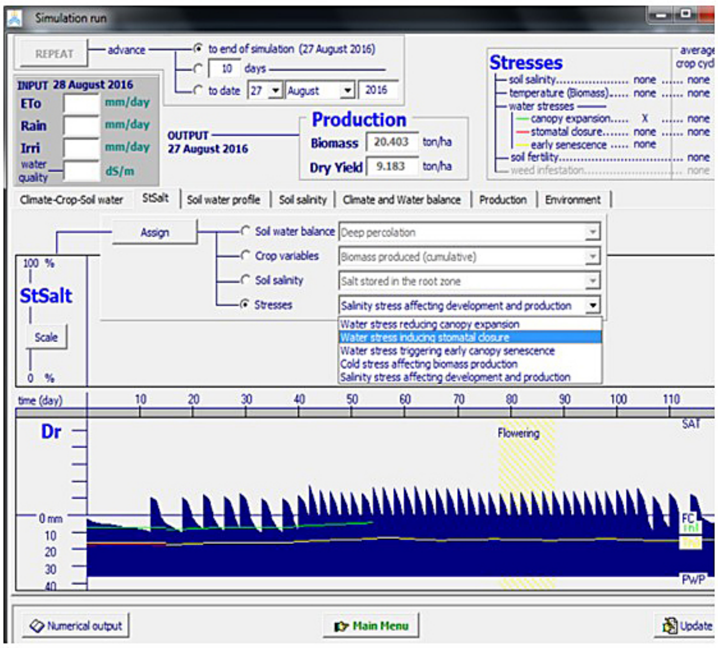

Figure 5. Features of the window for controlling salt and water balances

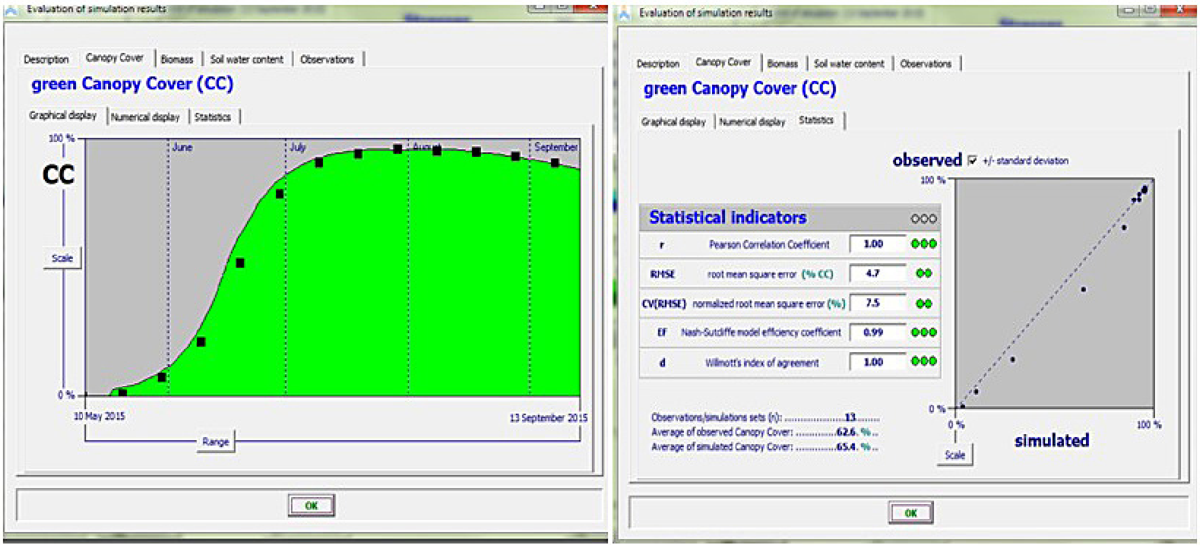

Figure 6. Evaluation of modeling of crop cover of Vicont rice variety

After the initiation of modeling, AquaCrop compares the simulated indicators with field data and provides Pearson's correlation coefficient (r), root mean square error (RMSE), normal correlated root mean square error (CV (RMSE)), coefficient of efficiency model (NF) for the Nash-Sutcliffe model and the Wilmot Treaty index (d). Figure 6 shows the results of the evaluation of simulated (line) and actual (points) data with corresponding standard deviations (vertical lines) relative to the CC of rice in the "Evaluation of modeling results" menu.

CONCLUSIONS

Components of rice cultivation process were established with simulation modeling. Convenience, accuracy and reliability of the developed model for management, modeling and decision-making from the perspective of yield formation of Vicont, Premium, Ukraine-96 rice varieties as well as development of irrigation regimes for effective agricultural production were demonstrated. Adaptation of the information provided by AquaCrop on studied rice varieties allowed automatic and sufficiently accurate generation of biologically optimal irrigation regimes for Vicont, Premium and Ukraine-96. Yields and water productivity of aforementioned rice varieties were also compared in the experiment, with the highest values for both parameters achieved by Vicont – 9.5 t/ha and 1.29 kg/m^3, respectively.

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