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Aquacrop model evaluation for generation of irrigation requirement for winter wheat cultivars

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Abstract: Research on water-saving techniques in agriculture is brought forward because of water resource shortages. Optimising irrigation strategies to increase water-use efficiency is an essential factor in water security for the Békés region in Hungary. FAO's AquaCrop model was used to improve water efficiency by simulating crop growth. In our study, the model was calibrated with the field measurements of the MATE ÖVKI Lysimeter Research Station. Four winter wheat varieties were cultivated under non-limiting water conditions. The yields ranged from 5.0 t/ha to 7.6 t/ha in the harvest on the 6th of July 2020. The crop growth was simulated with the actual climatic, vegetation, soil profile, and groundwater data. The AquaCrop simulation resulted in a similar yield data range, with a water productivity range of 1.07-1.23. The crop cycle of the plants was 187 days, while the harvest index was 45% in the model settings. The results led to the conclusion that water optimisation based on climate data and crop yield can help us generate net irrigation requirements. The generation of sprinkler irrigation schedules developed from this research would provide information for farming communities to mitigate the adverse effect of climate change.

Keywords: AquaCrop, irrigation, water productivity, wheat, efficiency

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Introduction

Advance in technology offers help in analysing natural processes. Increase of agricultural productivity essential to meet worldwide food demand. Water from precipitation or irrigation is needed to maintain the soil moisture available for the plants. Water is in continuous circulation, which leads to a dynamic change of water resources (Brouwer & Heibloem, 1986), strongly influenced by actual water use.

Surface and groundwater sources are exploited for domestic, industrial, and agricultural uses, where agriculture is the largest water user, representing around 75% (Wallace, 2000) of the total water extraction. As the world population grows (United Nations, 2019), the available agricultural land has decreased from 0.38 to 0.28 ha person-1 in the period from 1970 to 1999 (Howell, 2001). The farmers' attempt to adapt to the more frequent weather fluctuations can help meet food demand with increased productivity. Agricultural production is more and more influenced by climate change, where extremities can negatively affect crop production, resulting in a significant loss of yield.

Farming adaptation should focus on water management issues related to crop evapotranspiration, water shortages during the vegetative periods, increased likelihood of flood-

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ing, and reduced water sources (Iglesias & Garrote, 2015). Water use efficiency can be increased by knowing water requirements to find the optimal irrigation timing (Wang et al., 2018).

Irrigation efficiency by flooding is up to 70%, spraying 80%, and micro-irrigation 90%-96%. Water management in crop production is considered a powerful tool to achieve production stability, which can be supported by simulation of the water balance of the root zone during the vegetative period of the crops, using data as described by Raes et al. (2018) in the AquaCrop model.

Different objectives can be taken into account when designing an irrigation system at the field level, such as maximising the benefits and minimising the costs (Holzapfel et al., 2009). Properly validated AquaCrop simulations can determine the field variations of the yield. Abedinpour et al. (2014) described an example for maise, where AquaCrop showed the variations in yield in different scenarios.

Cereals, especially wheat, triticale, and maise, are important crops worldwide for food and feed production. Plant water requirements during the dry and wet years differ for crops and seasons. Zhao et al. (2021) described that higher yield co be achieved by applying irrigation but only to a certain limit where additional amounts of irrigation start to cause a decrease in the yield. Pre-sowing irrigation significantly increased soil moisture for winter wheat, and it positively affected yield in dry conditions. In arid arable lands, water use efficiency increased significantly with the decreasing irrigation level (Salemi et al., 2011) and decreasing crop evapotranspiration (ETc). Therefore, a practical analysis of how to reach a maximum yield is important; otherwise, irrigation could reduce productivity and water use efficiency.

Gravitational force and capillarity drive primarily the water movement in the soil. Physical properties of the soil define how these forces can move or store water in the pores, represented in the pF curve. AquaCrop handles it through its characteristic points. Optimally, the moisture content of the root zone should be around the soil's field capacity (water-holding capacity). When it is around the wilting point, different plants can tolerate water stress differently, as defined in the model's plant parameters. Agricultural management practices, like tillage (Sárdi, 2011), can also affect the actual moisture content of the root zone. Thus, those are also simulated in the model.

The AquaCrop model (Raes et al., 2012; Vanuytrecht et al., 2014) was enriched continuously with an improved parameterisation for solving complex tasks. For example, recently, it was successfully used by Guo et al. (2021) to analyse and optimise irrigation scenarios in a large region. The results showed that the optimised irrigation schedule performed better than the irrigation the farmers applied.

AquaCrop also has been used widely to compute crop water requirements (Saccon, 2018) using the FAO Penman-Monteith calculation (Pereira et al., 2015). It was shown that the effect of climate change has a negative impact on agricultural production and forestry.

In the present study, we are looking into the possibilities of AquaCrop to support farming with information on how to increase irrigation efficiency and productivity. The objective is to improve yield while maximising crop water productivity for four wheat varieties. The optimised irrigation schedule contains reallocated irrigation times between different simulation regions and improved water resource allocation.

Materials and Methods

Field experiments were conducted at the Lysimeter Research Station of MATE ÖVKI in Szarvas, Hungary, during the 2020 growing season. The climate in this area is continental. Figure 1 shows the temperature data for the wheat growing season received from the meteorological station at the Lysimeter Research Station for 2020. The precipitation data is presented in Figure 2. The soil type of the study area is clay loam. The MATE ÖVKI agronomic measurements were applied to quantify the biomass parameters.

For this study, the FAO's AquaCrop model was calibrated for the calendar mode and verified with field data of two drought-resistant ('GK Berény' and 'Plainsman V.') and two drought-sensitive ('Midas' and 'PC 84') wheat varieties cultivated at the Lysimeter Research Station. The post-harvest data were compared to those stimulated in AquaCrop 6.1. The modelling framework needs crop information, climate data, soil information and field management, as described by Steduto et al. (2012). We have simulated wheat yield production in different scenarios and water productivity in the model. The input parameters required defining the data for each wheat variety, such as the sowing, seedling, jointing, flowering date, filling to the maturity date and root depth. The wheat production in 2020, as the analysis of the Hungarian Central Statistical Office (HCSO, 2020) showed, was outstanding, higher than in the previous years. From simulated runs, it was evaluated whether irrigation is needed for wheat varieties by the sprinkler method. Different time steps and irrigation amounts were compared based on the allowable depletion percentage of readily available water content in the root zone.

Results

Our study used the AquaCrop model for modelling winter wheat development under certain climatic conditions and irrigation to boost yield and water productivity. Crop parameters were defined using field data from the Lysimeter Research Station. The results show a good representation of the crop varieties and their field performance, similar to the research of Guo et al. (2021).

Non-limiting sprinkler irrigation (Andarzian et al., 2011) was simulated. The irrigation scheduling and timing were set at different scales.

Figure 1 shows the air temperature measured by an automatic weather station (Agromet Solar, Boreas Ltd., Hungary). The mean temperature was 13.3 °C, the minimum was 7.6 °C, and the highest reached 34.9 °C. The dormant phase for wheat varieties starts at 0 °C based on (Porter & Gawith, 1999). The weather extremes stayed inside the cultivar tolerance for production. The average relative humidity for the research was set to 75.9%.

Soil parameters were set to clay-loam (Soil Survey Staff, 1999). Sowing and planting in rainfed farming are primarily based on the rainfall and soil water holding capacity. Weather conditions vary from year to year. Considering that the soil is the ideal environment for plant growth, the average factor input from the Lysimeter Research Station and other fields. The optimum balance between the parameters and input methods to calculate measured data based on a complex process with an accurate yield simulation. The soil model was customised to clay loam texture with 0.03% total salinity and 1.31% on total organic carbon content to represent the growth medium of four wheat cultivars.

Figure 2a) shows the monthly precipitation averages from 1971 to 2000, based on the data collected from the Hungarian Meteorological Service (Met.hu, n.d.). The annual average is 570 mm, where the summer months have higher and the early spring months show lower precipitation. Figure 2b) shows the data for 2020 from January to September measured at the experimental site. Periodic soil water monitoring reflected that the precipitation was relatively high in 2020. The metrological station measured,

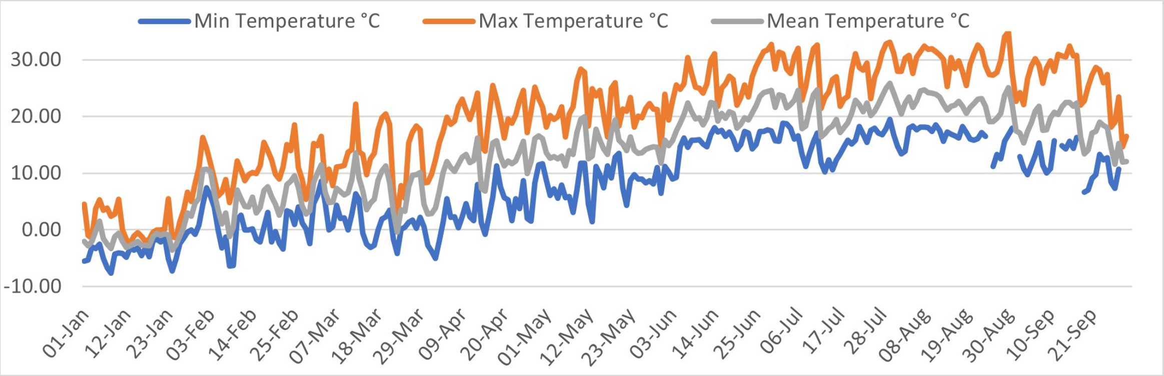


Figure 1: Weather station temperature data of the study area

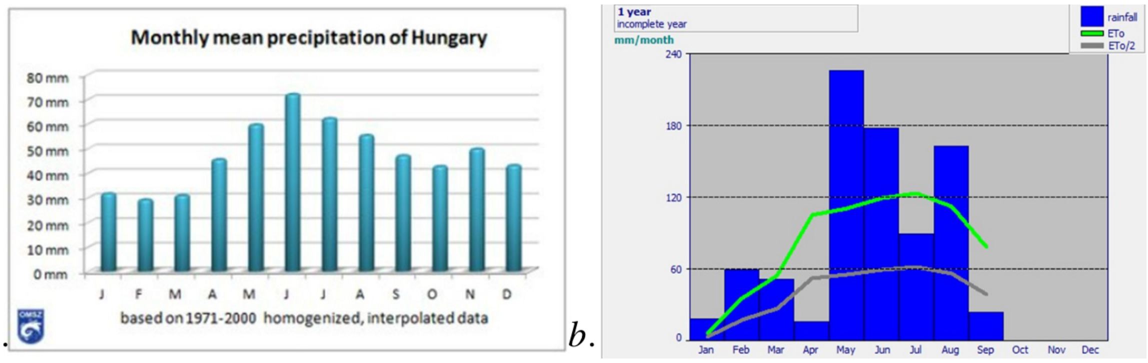


Figure 2: Precipitation a) Monthly averages (1971-2000) (Met.hu, n.d.); b). Actual in situ measurements (January-September 2020) for the location

from January to September, a total rainfall of 827 mm, whereas during the cropping period (the length of it was 187 days), the rainfall was 572 mm.

Daily biomass production and yield response were simulated in the model for wheat, which is an annual crop product. Drought directly reduces crop yield by decreasing the water availability in soil or by decreasing the relative humidity, which increases crop transpiration (Taiz & Zeiger, 2002). Plant water stress occurs when the soil moisture drops below a crop-specific level and the stomatal closure starts. Shams (2022) investigated the effect of climatic stresses on grain spikes under deficit irrigation, where irrigation scheduling is based on the estimation and measurement of soil moisture.

Our focus was on the effects of water retention and soil water movement on biomass production, harvest index, and potential biomass to compare the extension to the farm-scale. Our wheat varieties were not significantly different from the observed and simulated data of Guendouz et al. (2014). Therefore, in cases of limited input factor under semi-arid conditions, the AquaCrop model is promising for estimating crop productivity. The AquaCrop field measurement and modelled data did not show significant differences in our research field. Modelled potential ETo in our model was of 762 mm (Figure 3), while achieved average in each variety is 472 mm of crop evapotranspiration.

The graphs of Figure 4 show that the soil water content stayed relatively close to the

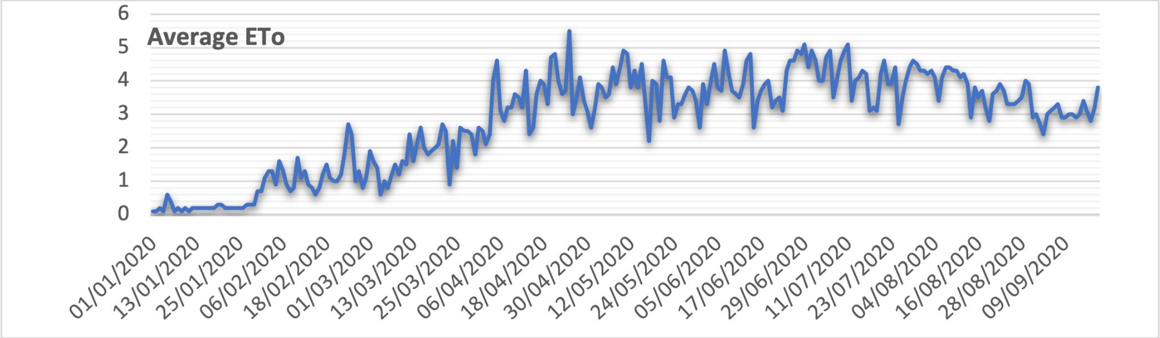


Figure 3: Reference ETo computed in AquaCrop from daily meteorological data of the station

field capacity. This resulted from a very wet year. The produced biomass average of the four varieties was around 6,310 kg. The yields in the research field were achieved in the level of 6.2 tons, 5.0 tons, 6.4 tons, and 7.7 tons, compared to the average grain yield per hectare for the Hungarian climate (Karacsony & Markus, 2007) which were lower (3 to 5 tons). On figure 5 and table 1 when comparing to the simulated irrigation events on AquaCrop for soil moisture, the predicted year had higher precipitation and favourable weather for wheat production. On the contrary, for AquaCrop data calibration, we have achieved the same outcome regarding yield measurements. Scenario analysis of the wheat varieties indicated water productivity (table 1) ranging from 1.17 to 1.14 kg m^{-3} and a yield of 6.1 to 6.2 t ha^{-1} for Plainsman V variety. For variety PC 84 the ET water productivity was at 1.07 and yield ranged from 5,083 to 5,106 kg ha^{-1}. Values from other simulation had minor increases from the first simulative data on AquaCrop.

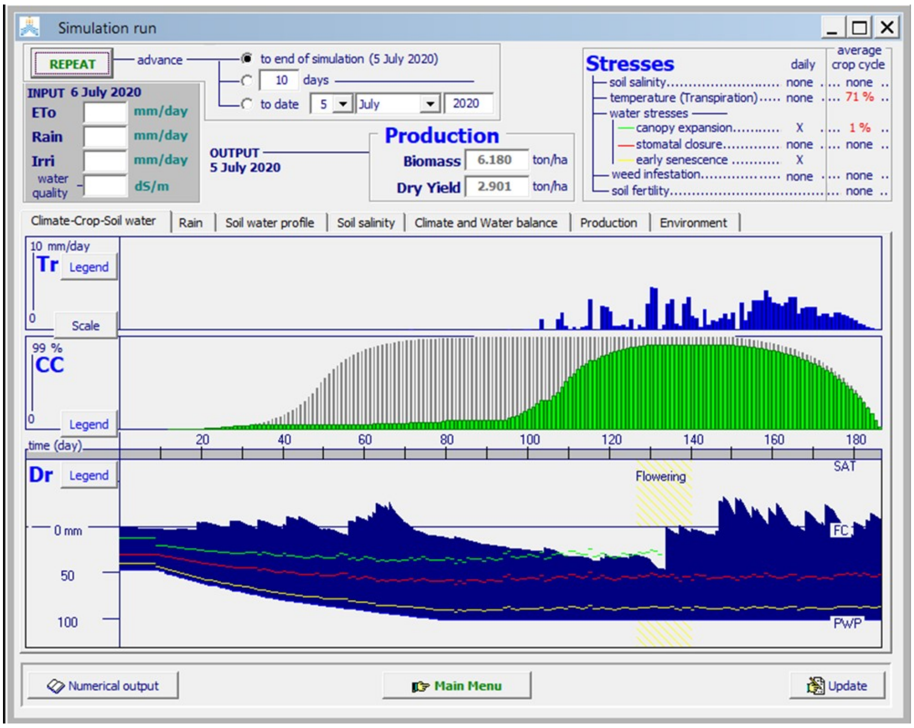
In intensive agriculture, it is important to have stable water sources for sustainable production. A decline in water sources enhances the efforts to increase water use efficiency (Wang et al., 2018), which results in high yield production. Irrigation efficiency is one of the crucial factors to pay attention to in extreme agricultural conditions.

The simulation results of three scenarios for the four wheat varieties are shown in Table 1. Sprinkler irrigation was applied when the root zone soil moisture dropped below a selected level. It was in the first scenario 60%, the second scenario 75%, and the third scenario 85% of the field capacity. These scenarios were simulated on the four cultivars under the same meteorological conditions, field management, soil profile, and other factors.

Conclusions

After analysing the results, we may conclude that the yield increase was negligible due to the meteorological circumstances at the time of planting was carried out using the paralleling test. Each simulation has provided sufficient outcome regarding harvest index, potential biomass and achieved biomass.

In this study, four wheat varieties cultivated at the MATE ÖVKI Lysimeter Research Station (Szarvas, Hungary) were simulated using the AquaCrop model to describe the growth cycle of winter wheat using three irrigation patterns. Climate, crop, soil, and field management data were defined at the test area for our study. In the growth period, rainfall satisfied the water need for wheat production in the observed year. Furthermore, none of the irrigation schedules resulted in a substantial boost in production.



Simulation run

advance ● to end of simulation (5 July 2020)

○ 10 days

○ to date 5 July 2020

INPUT 6 July 2020

ETo mm/day

Rain mm/day

Irri mm/day

water quality dS/m

OUTPUT 5 July 2020

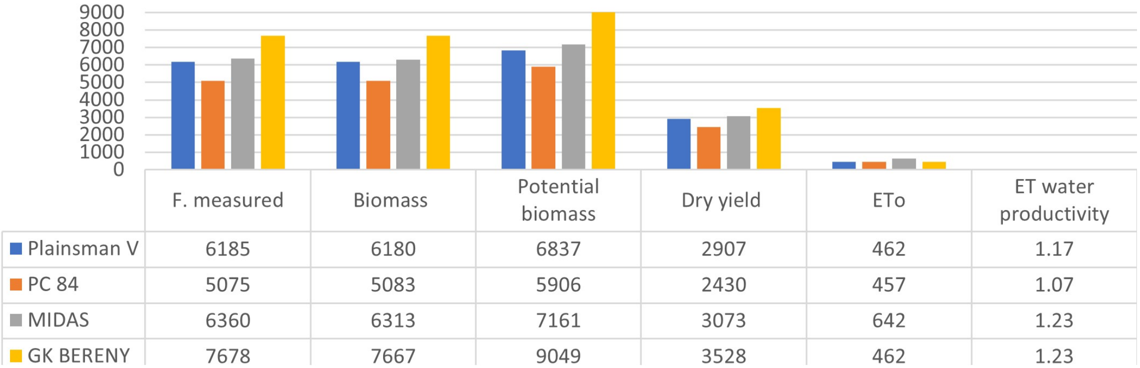
Production

Biomass 6.180 ton/ha

Dry Yield 2.901 ton/ha

Stresses	daily	average crop cycle
soil salinity	none	none
temperature (Transpiration)	none	71 %
water stresses		
canopy expansion	X	1 %
stomatal closure	none	none
early senescence	X	
weed infestation	none	none
soil fertility		none

Figure 4: The simulation results of Plainsman V in AquaCrop



	F. measured	Biomass	Potential biomass	Dry yield	ETo	ET water productivity
Plainsman V	6185	6180	6837	2907	462	1.17
PC 84	5075	5083	5906	2430	457	1.07
MIDAS	6360	6313	7161	3073	642	1.23
GK BERENY	7678	7667	9049	3528	462	1.23

Figure 5: Basic simulation run for the wheat varieties for biomass, dry yield, and potential biomass

Modelled vegetation year had a more than average precipitation and favourable weather for wheat production, characterising the most favourable conditions for wheat production. It reached a yield close to the potential genotype yield. Nevertheless, AquaCrop properly simulated the dynamics of soil moisture of the rootzone, crop biomass, and grain yield. The usefulness of the AquaCrop software to model the crop growth in Hungarian circumstances was proved.

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Table 1: Aquacrop generation net irrigation water requirements

Irrigation (mm of water)	Plainsman V	PC 84	MIDAS	GK BERENY
Basic Simulation	No irrigation			
Gen-60%	57	55	59.3	57.7
Gen-75%	40	39.7	39.7	39.5
Gen-85%	40	39.7	45.5	46.4
Water productivity				
Basic Simulation	1.17	1.07	1.23	1.23
Gen-60%	1.14	1.04	1.20	1.19
Gen-75%	1.16	1.07	1.23	1.22
Gen-85%	1.16	1.07	1.24	1.23
Yield (kg/ha)				
Basic Simulation	6180	5083	6313	7667
Gen-60%	6198	5106	6342	7718
Gen-75%	6189	5098	6335	7705
Gen-85%	6189	5098	6327	7689

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