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# Validating AquaCrop model for rainfed and irrigated maize and soybean production in eastern Croatia

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**Abstract**— In this study, the AquaCrop model was used to quantify climate change impact on yield and net irrigation in maize and soybean production. Daily observed climate data (1961–1990) from Osijek weather station were used for past climate simulation, and output data from ECHAM model were dynamically downscaled under two IPCC SRES scenarios (A1B, A2) for two integration periods 2041–2070 and 2071–2100. The soil properties and crop data were presented from 6-year-long (2010–2015) field study of the Agricultural Institute in Osijek, Osijek-Baranja County. The climate results showed expected rise in air temperature up to 5 ºC and significantly lower precipitation up to 43.5%. According to results from the AquaCrop model, there is no change in maize yield in non-irrigated conditions, while in irrigated conditions there is a yield increase of 1.4 t ha⁻¹ of dry matter (dm), with 80 mm higher net irrigation in comparison with the 1961–1990 period. As for soybean production, the increase in yield is expected in both non-irrigated and irrigated conditions. The yield increases up to 1.9 dm t ha⁻¹ in irrigated conditions with 90 mm higher net irrigation in comparison with the 1961–1990 period. As for crop water indices, in non-irrigated conditions the water use efficiency (*WUE*) has a trend to decrease in the future, while in irrigated conditions it can slightly increase. Irrigation water use efficiency (*IWUE*) showed significantly higher increase in irrigated maize and soybean production.

*Key-words:* climate change, maize, soybean, yield, net irrigation, water efficiency

## 1. Introduction

Farms in Croatia can be characterized as considerably smaller than the EU average (14.4 ha) considering that the average farm size is 5.6 ha per holding, where one half of holdings are less than 2 ha (*Eurostat*, 2017). This fact is one of the most important specific restrictive effects on expansion of irrigation areas in Croatia. According to the recent published official data, in Croatia only 13,430 ha (1.4% of arable lands) is irrigated (*MEE*, 2014). In the Osijek-Baranja County, the study region, total equipped area for irrigation is 1,390 ha, whereby 512 ha with groundwater, while 878 ha with surface water (*Crostat*, 2006). Future expansion of irrigation areas in Croatia is encouraged by government and policy measures, so the goal is to provide infrastructure to implement irrigation on 65,000 ha of arable lands until the year 2020 (*Holjević et al.*, 2008). In Croatia, irrigation is manly used on supplementary basis to improve production of summer crops. Above 56% of agricultural areas in Croatia are categorized as arable lands, while in Osijek-Baranja County nearly 95% (200892 ha). Total agricultural land in Osijek-Baranja County is 212,095 ha, whereby 200,892 ha is arable land. In average 60.8% of arable lands are sown with maize, while 14.6% with soybean. The considerable yield variation of summer crops is mainly caused by unfavorable weather conditions. Not only because of the lack of rainfall but because of the dry periods which prolonged for fifteen years, local authorities proclaimed natural disaster of drought (2000, 2003, 2007, 2011, 2012, 2013, and 2015). According to *Perčec Tadić et al*. (2014) among all natural hazards in Croatia, drought causes the largest economic losses (39%). A more detailed analysis of drought phenomena in the Republic of Croatia have been done by *Cindrić et al*. (2016). Authors claim that the examined 2011/2012 drought in Osijek-Baranja County was characterized by extremely long duration with the highest magnitudes since the beginning of the twentieth century. *Branković et al*. (2009) have stated that during the twentieth century, the decline in annual amounts of precipitation in Osijek area is –4.1% in spring and –3% in autumn. As a result, in dry growing seasons, the yields of main summer crops grown in farm conditions are reduced as follows (*CBS*, 2018): maize yield was reduced by 39.7% (2010), 38.3% (2003), 28% (2007), 1.2% (2011), 22.1% (2012), 4.5% (2013), and 4.2% (2015), while soybean yields were reduced by 41.7% (2010), 29.3% (2003), 20.8% (2007), 25% (2013), and 8.3% (2015). Therefore, the importance of irrigation practice in this region is unquestionable. Furthermore, the yields of summer crops in several field studies are considerably increased by compensating the lack of rainfall with irrigation water. Some previously published results have evaluated the effect of irrigation treatments on maize yield in the study region. For example, in full irrigated plots, which was set to achieve soil water content of 80 to 100% of field capacity (FC), maize yield was by 25% (2011) and by 40% (2012) higher compared to control (dryland) plots (*Marković et al.*, 2015). As for soybean, in full irrigated plots

yields were by 9.4% (2007), 12.2% (2009), 46% (2012), and 18.8% (2013) higher compared to control plots (*Josipović et al.*, 2011, 2013). The irrigation efficiency (IE) is usually interpreted as the yield increase or reduction in irrigated agriculture. According to *Irmak et al.* (2011), irrigation efficiency (IE) is generally defined from three points of view: (1) the irrigation system performance, (2) the uniformity of water application, and (3) the response of the crop to irrigation. Some DSSAT crop simulations were done in term of climate changes and influence on maize production, and it was shown that in the future Croatia would belong to the area of decreased maize yields (*Vučetić*, 2008). The maize yield was simulated in non-irrigated conditions. This research emphasizes the importance of adaptation for summer crop production in terms of implementation of irrigation practice. The AquaCrop model was chosen in this paper to simulate the non-irrigated and irrigated production as the adequate and ideal crop model for irrigation evaluation, developed by Food and Agriculture Organisation of United Nation (FAO). According to *Farahani et al.* (2009), the FAO AquaCrop model provides a theoretical framework to investigate crop yield response to environmental stress, especially water and salinity. It simulates soil water balance and crop growth processes, based on input parameters and data, as a function of climate, soil, and plant interaction (*Foster et al.*, 2017). The model precisely simulates the crop production, as it operates on a daily input data. In literature, AquaCrop model is well known in research community and successfully validated through many regions and various crops for field production: wheat (*Rezaverdinejad et al.*, 2014), maize (*Ahmadi et al.*, 2015; *Paredes et al.*, 2014; *Stricevic et al.*, 2011), sugar beet (*Stričević et al.*, 2014), and sunflower (*Todorovic et al.*, 2009) crop production. The aim of this paper was to validate the AquaCrop model in non-irrigated and irrigated maize and soybean production for climate and soil conditions of Osijek-Baranja County (eastern Croatia). In the next step, the AquaCrop model was used to simulate maize and soybean production for future climate conditions for the 2041–2070 and 2071–2100 periods. Further results are presented: (a) the relative change in yield of maize and soybean in non-irrigated and irrigated conditions; (b) the change in net irrigation, water use efficiency (*WUE*), and irrigation water use efficiency (*IWUE*).

## 2. Materials and methods

### 2.1. Location

The field study was conducted at the research site of the Agricultural Institute in Osijek (45º32'N and 18º44'E). The area of Osijek (Osijek-Baranja County, eastern Croatia) has an altitude of 90 m. According to the Köppen climate classification system, the climate of Osijek is classified as moderately continental climate (Cfwbx) with an average annual precipitation of 650 mm, an

average air temperature of 10 ºC, and an annual sunshine of 1649 h. Mentioned climate data are expressed as an average for the 1961–1990 period. The soil is classified as gleysol (hydro-meliorated) WRB with its main characteristics presented in *Tables 1* and *2*. The soil analyses included mechanical, chemical, and soil water characteristics, sampled in two to four profile depth.

*Table 1*. Mechanical and hydrological characteristics of the soil at the research site

| Profile (cm) | Clay (%) | Silt (%) | Sand (%) | BD (g/cm$^3$) | PWP (vol.%) | FC (vol.%) | SAT (vol.%) | TAW (mm) |
|---|---|---|---|---|---|---|---|---|
| 0–32 | 32.5 | 64.7 | 2.8 | 2.58 | 23.65 | 36.57 | 39.52 | 129 |
| 32–50 | 31.3 | 66.4 | 2.3 | 2.65 | 24.52 | 35.59 | 40.88 | 110 |
| 50–70 | 25.5 | 68.2 | 6.3 | - | - | - | - | 200 |
| 70–105 | 21.6 | 71.8 | 6.6 | - | - | - | - | 200 |

BD = bulk density; PWP = permanent wilting point; FC = field capacity; SAT = saturation; TAW = total available water

*Table 2*. Chemical characteristics of soil at the research site

| Profile (cm) | Organic carbon (%) | Nitrogen (%) |
|---|---|---|
| 0–40 | 0.91 | 0.13 |
| 40–95 | 0.77 | 0.13 |

## 2.2. Past and future climate data

The past climate (1961–1990) presents daily weather data, observed at the weather station Osijek (45º32'N and 18º44'E) located nearby the experimental field. The data set includes maximum and minimum air temperature (ºC), insolation (h), precipitation (mm), vapor pressure (mbar), and wind speed (m/s). The reference evapotranspiration was calculated applying the FAO Penman-Monteith method (*Allen et al.*, 1998). For the future climate conditions, the data were assumed from the integrated coupled model ECHAM, developed at the Max Planck Institute for Meteorology (*Roeckner et al.*, 2003). The modeled data

were dynamically downscaled for two periods: from 2041 to 2070 and from 2071 to 2100. All simulations were done under the A1B and A2 (*IPCC*, 2001) scenarios for greenhouse gas (GHG) emissions for two the integration periods mentioned above, considering $CO_2$ effect. The average $CO_2$ concentration was 333.4 ppm for the 1961–1990 period, 545.7 mm (A1B scenario) and 551.0 ppm (A2 scenario) for the 2041–2070 period, and 662.4 ppm (A1B scenario) and 731.1 ppm (A2 scenario) for the 2071–2100 period.

## 2.3. Field study and crop management

Maize and soybean yield data, presented in this paper, were observed from a long-term field experiment for the 2010–2015 period. For the purpose of this study, yield data are presented for maize hybrids FAO 500 and 600, and soybean varieties 0–1 group. The region and field plots as well as the crop management were previously presented by *Josipović et al.* (2013) and *Marković et al.* (2017). Planting date, density, as well as observed phenology (sowing, emergence, flowering, and maturity) are presented in *Table 3*. The size of the maize hybrid plot was 19.6 $m^2$. Each year, maize hybrids were planted at 0.7 m row spacing, 0.25 m inter-row spacing, and depth of approximately 5 cm. The size of the soybean variety plot was 30 $m^2$. Seeding density for soybean crop was 550 seeds/$m^2$. Grain yield for both crops was measured after harvesting of each experimental plot, adjusted to 14% grain moisture and expressed as kg $ha^{-1}$.

Since the maize and soybean yield data for this study are expressed for irrigation treatment, here follows a more detailed description of the irrigation scheduling. Studied irrigation treatments included dryland ($I_0$-control) in both crop production, while the irrigated plot was designed to irrigate at 60–80% field water capacity (FWC) for maize ($I_1$) (*Hoogenboom et al.*, 2012) and 80–100% FWC ($I_2$) for soybean, which is more vulnerable on the deficit in soil moisture. The size of irrigation plots for maize crop was 78.4 $m^2$, while for soybean it was 120 $m^2$. Irrigation was scheduled with the use of Watermark soil moisture sensors (model 200SS). The sensors were set up at two depths (15–20 cm and 25–30 cm) after the maize and soybean sowing, and were kept in soil until the harvest time. The Watermark sensors were calibrated for the soil on a trial site by comparing gravimetric measurements and sensor readings (*Marković*, 2013). The calibration curve is presented in *Fig. 1*. The maize and soybean were irrigated by use of traveling sprinkler system, which performed at the average speed of 15 m $h^{-1}$ and provided 35 mm of irrigation water (1.5 l $min^{-1}$). Total amounts of water added in each growing season and irrigation treatments are presented in *Table 3*. Water for the system was pumped from 37 m deep well at a 5 to 7 l $s^{-1}$ flow rate using an electric pump (5.5 kW). The analysis of chemical quality of irrigation water showed that the composition and concentrations of salts do not induce toxicity problems. The analysis was

interpreted according to FAO standards (*Ayers* and *Westcot*, 1985). The irrigation water use efficiency (*IWUE*) was determined as

$$IWUE = \frac{(Y_d - Y_i)}{I},$$

(1)

where *IWUE* is the irrigation water use efficiency (kg m$^{-3}$), *Yd* is the yield (kg) on dry plots, *Yi* is the yield (kg) on irrigated plots, and *I* (m$^3$) is the net irrigation water (*Nakayama et al.*, 1979). The water use efficiency (*WUE*) was determined as

$$WUE = Y / ET_0 ,$$

(2)

where *WUE* is the water use efficiency (kg m$^{-3}$), *Y* is the economic yield (kg m$^{-3}$) for irrigation level, and *ET$_0$* (m$^3$) is the reference crop evapotranspiration (*Kang et al.*, 2000). The reference crop evapotranspiration (*ET$_0$*) was calculated according to the Penman-Montheith method by using the AquaCrop model.
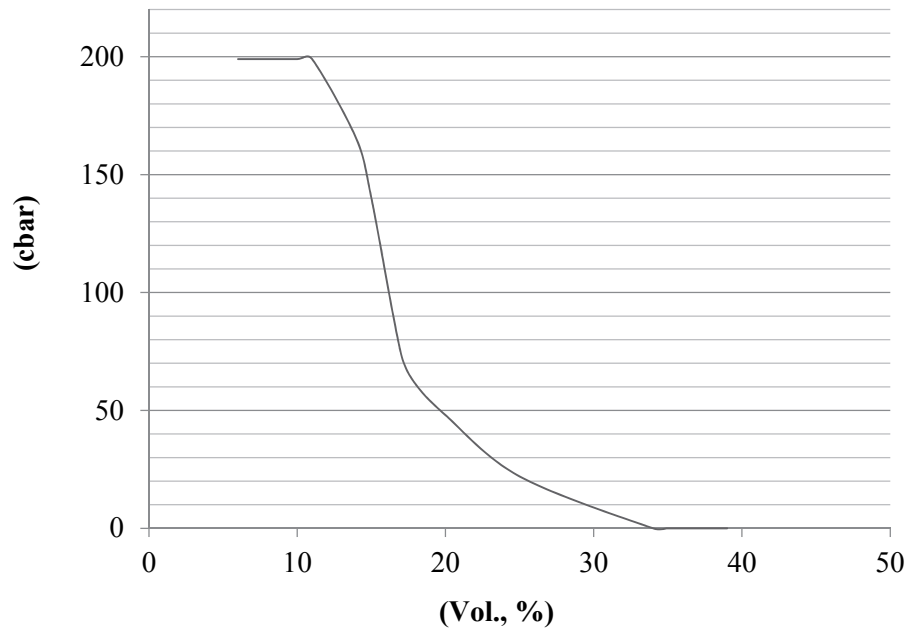


*Fig. 1*. Calibration curve of the Watermark sensors for the soil type at the study site. (*Marković*, 2013)

*Table 3*. Planting date, density, and observed phenology for maize and soybean crops

| Year | Plant density (plant/m²) | Sowing (date) | Emergence (date) | Flowering (date) | Harvest (date) | Precipitation (mm) | Irrigation (mm) |
|---|---|---|---|---|---|---|---|
| **Maize** | | | | | | | I₁ |
| 2010 | 5.84-5.31 | May 6 | May 16 | July 26 | Oct 5 | 605.1 | 35 |
| 2011 | 5.98-5.87 | May 3 | May 15 | July 14 | Sep 25 | 210.7 | 105 |
| 2012 | 5.89-5.36 | Apr 28 | May 6 | July 29 | Sep 15 | 247.2 | 175 |
| 2013 | 5.92-5.38 | Apr 30 | May 12 | July 21 | Oct 2 | 388.3 | 105 |
| 2014 | 5.71-6.42 | May 6 | May 18 | July 25 | Oct 4 | 395.0 | 140 |
| 2015 | 6.02-6.45 | Apr 30 | May 11 | July 27 | Sep 20 | 292.2 | 140 |
| **Soybean** | | | | | | | I₂ |
| 2010 | 59-61 | Apr 28 | May 5 | June 24 | Sep 20 | 522.7 | 105 |
| 2011 | 60-64 | Apr 20 | May 2 | June 8 | Sep 8 | 216.4 | 245 |
| 2012 | 59-64 | Apr 27 | May 3 | June 16 | Sep 6 | 215.4 | 245 |
| 2013 | 60-62 | Apr 25 | May 5 | June 20 | Sep 12 | 252.1 | 210 |
| 2014 | 59-62 | May 6 | May 18 | June 19 | Sep 20 | 457.7 | 175 |
| 2015 | 58-62 | Apr 21 | May 5 | June 12 | Sep 10 | 280.7 | 210 |

## 2.4. Data analyses

Two statistical methods were used to analyze, evaluate, and compare observed yield data from field experiments and simulation yield results, to measure the AquaCrop model goodness of fit in our environmental conditions. First the relative deviation (*Törnvist et al.*, 1985) was calculated between the simulated and observed dry matter yields for each year. The method was chosen to show how the model works and its sensitivity to various climate conditions each year under the same or similar crop management activity:

$$r = \frac{(S-M)}{(M \times 100)},$$ (3)

where *r* is the relative deviation (%), *M* is the observed yield (dm t ha⁻¹), and *S* is the simulated yield (dm t ha⁻¹). The crop model fits when *r* is less than 15% (*Tsuji et al.*, 1998). The second method selected for quantitative summary of goodness of fit was the root mean square error (*RMSE*):

$$RMSE = \sqrt{\left(\frac{1}{n}\right) \sum_{i=1}^{n}(y_i - \hat{y}_i)^2},$$ (4)

where *RMSE* is the root mean square error (dm t ha⁻¹), $y_i$ is measured value, $\hat{y}_i$ is the corresponding simulated value, and *n* is the number of measurements (*Wallach et al.*, 2018). The *RMSE* has the same unit as the measured value *y*.

## 2.5. AquaCrop model, input data, calibration, and validation

The AquaCrop model is developed by FAO to simulate the crop response on the environmental stress. It is described by *Steduto et al.* (2009) in details. The model calculates daily biomass based on daily transpiration data, using reference evapotranspiration ($ET_0$), and normalized water productivity. The simulated yield is calculated as the product of daily biomass using the harvest index (HI). As the water is of the main importance in the AquaCrop model, it also simulates the changes in the soil water content during the growing season by means of a soil water balance. The soil water balance consists of the incoming water (rainfall, irrigation, and capillary rise), and outgoing water (runoff, evapotranspiration, and deep percolation) contained in different profiles of soil root zone depth. The moment for irrigation is possible to be calculated in the model, as the fixed amount of water retained and depleted in the root zone at any moment of the season. That possibility gives an opportunity to simulate irrigation efficiency on crop productivity (*Greaves* and *Wang*, 2017). To safely use simulation results by the AquaCrop model, it is necessary to do local calibration and validation for the chosen crop. The model requires a relatively small number of input data which describes the soil–crop–weather environment in which the crop develops (*Stricevic et al.*, 2011). Using input data, observed daily weather data, soil characteristics, field management data, and crop parameters, the AquaCrop model was calibrated for maize and soybean production. For maize production, the model version 5.0 provides files with parameters suitable for the simulation of maize production, but with default values. These values were chosen only as a starting point, then the final key parameters were modified to fit the local crop management. All crop parameters were calibrated for the FAO 500–600 type maize hybrids, so that the crop model may simulate and present the real crop production in our local conditions. In *Table 4* final parameters are given, which are used for AquaCrop model calibration for maize and soybean production. Initial canopy cover was 0.37% with maximum canopy cover 96% in maize production (*Table 4*). The base air temperature was set to 8 ºC and the upper temperature to 30 ºC. Water productivity was 33 g m² and harvest index was 44% (*Table 4*). The crop management was standard for our agro-ecological conditions for maize and soybean growing. Soil fertility was considered as sufficient to achieve an ideal yield genetic potential, thus we could estimate only the effects climate change conditions. Net irrigation for maize and soybean is presented in *Table 3*. The AquaCrop model was calibrated for maize production for year 2010, results are and shown in *Table 5*. The relative deviation between the non-irrigated observed

and simulated dry matter yields was 3%, and it was 3.9% between the irrigated observed and simulated yields. The absolute change for net irrigation was 20.7 mm.

*Table 4*. Default and final parameters for the Aquacrop model calibration for maize and soybean production

| Description | Maize default | Maize final (value) | Soybean default | Soybean final (value) | Units/meaning |
|---|---|---|---|---|---|
| Base temperature | 8 | 8 | 5 | 8 | ºC |
| Cut-off temperature | 30 | 30 | 30 | 30 | ºC |
| Initial canopy cover ($CC_o$) | 0.49 | 0.37 | 1.65 | 2.95 | % |
| Canopy expansion (CGC) | 16.3 | 23.1 | 1.6 | 9.6 | % / day |
| Maximum canopy cover (CCx) | 96 | 96 | 98 | 98 | % |
| Canopy decline coefficient (CDC) at senescence | 11.7 | 11.7 | 2.9 | 2.9 | % / day |
| Water productivity. (WP*) | 33.7 | 33 | 16 | 16 | as fraction of TAW (%) |
| Reference harvest index ($HI_o$) | 48 | 44 | 40 | 30 | common for good conditions (%) |

*Table 5*. Calibration (2010) and validation of maize grain yield (dm t ha$^{-1}$) for the 2010–2015 period

| Year | Non irrigated | | | Irrigated | | |
|---|---|---|---|---|---|---|
| | Observed yield (dm t ha$^{-1}$) | Simulated yield (dm t ha$^{-1}$) | Relative deviation (%) | Observed yield (dm t ha$^{-1}$) | Simulated yield (dm t ha$^{-1}$) | Relative deviation (%) |
| 2010 | 7.9 | 7.7 | -2.5 | 7.9 | 7.6 | -3.9 |
| 2011 | 6.4 | 7.0 | 9.4 | 7.6 | 7.7 | 1.8 |
| 2012 | 6.4 | 5.7 | -10.9 | 7.7 | 7.8 | 0.8 |
| 2013 | 7.4 | 6.9 | -6.8 | 7.2 | 7.5 | 3.8 |
| 2014 | 10.5 | 7.8 | -25.7 | 11.9 | 7.8 | -34.2 |
| 2015 | 7.4 | 6.8 | -8.1 | 9.3 | 7.8 | -16.5 |

The validation was done for a six-year period from 2010 to 2015, at the same location (*Table 5*). The relative deviation between simulated and observed dry matter yields was calculated for each year according to *Törnvist et al.* (1985) indicating how model fits in various climate conditions under the same crop management. The relative deviation between non-irrigated simulated and observed yields varied from 3 to 11%, while in irrigated conditions from 0.8 to 16.5%, except in year 2014. The absolute change in net irrigation varied from 2.3 to 38.8 mm, except for 2014. The highest deviation in yield as well as the absolute change in net irrigation (93.9 mm) occurred in 2014. In that year, the number of rainy days was above the long-term average, with very significant higher precipitation at the end of the growing season.

This significant difference between simulated and observed yield values is a consequence of the model inability to simulate the plant reaction to stress in extreme conditions, such as high variations in daily air temperature and precipitation sum in short time intervals (*Lalic et al.*, 2011). The second method selected for quantitative summary of goodness-of-fit was the RMSE method (*Wallach et al.*, 2018). For the 5-year-long period (without the extreme weather year, 2014), it was 0.3 dm t ha$^{-1}$ under non-irrigated maize production and 0.4 dm t ha$^{-1}$ under irrigated maize production. The *RMSE* value was below 0.5 dm t ha$^{-1}$ and showed that the model fits under our environmental conditions. The AquaCrop model was also calibrated for soybean 0 to 1 maturity group variety for year 2011 (*Table 6*). The relative deviation between non-irrigated simulated and observed dry matter yields was 1% and 3.8% in irrigated conditions. Absolute change for net irrigation was 3.2 mm. The model was validated for the 6-year-long experiment at the same experimental field (*Table 6*). The relative deviation between simulated and observed yields varied from 0 to 9% in non-irrigated conditions and from 0.4 to 5.1% in irrigated conditions, except in year 2010, when the relative deviation was 22 and 25.2%, due to heavy precipitation. The absolute change for net irrigation varied from 1.6 to 30 mm, except in year 2014, when the precipitation was considerably higher than the long-term average at the end of the growing season. The *RMSE* for 6-year-long period was 0.07 dm t ha$^{-1}$ under non-irrigated conditions and 0.09 dm t ha$^{-1}$ under irrigated conditions, which improves the model validation under our environmental conditions.

To estimate the climate change impact on yield, net irrigation, and *WUE* in future conditions, it is necessary to keep same crop management operations and crop parameters in model as in the period of 2010–2015. The crop parameters and phenology stages, which were kept the same for the 1961–1990 period and future conditions are presented in *Table 7*. In the model, sowing and phenology were set at the average sowing date, emergence, maximum canopy cover, flower appearance and maturity date (*Table 7*). Additionally, under irrigated conditions, the readily available water was set to 80%, below which the soil water content in the root zone may not drop. This irrigation method in the model, including defined and set local soil hydrological characteristics, gave similar net irrigation quantities to measured net irrigation from field experiments.

*Table 6.* Calibration (2011) and validation of I group maturity soybean grain yield (dm t/ha) for the 2010 to 2015 period

| Year | Non irrigated | | | Irrigated | | |
|------|---------------|---|---|-----------|---|---|
| | Observed yield (dm t ha⁻¹) | Simulated yield (dm t ha⁻¹) | Relative deviation (%) | Observed yield (dm t ha⁻¹) | Simulated yield (dm t ha⁻¹) | Relative deviation (%) |
| 2010 | 2.9 | 3.5 | 22 | 2.8 | 3.5 | 25.2 |
| 2011 | 3.0 | 3.0 | -1 | 3.9 | 3.7 | -3.8 |
| 2012 | 2.4 | 2.5 | 5 | 3.7 | 3.7 | -0.4 |
| 2013 | 2.9 | 2.9 | 0 | 3.8 | 3.7 | -4.2 |
| 2014 | 3.1 | 3.3 | 7 | 3.5 | 3.7 | 5.1 |
| 2015 | 2.7 | 2.9 | 9 | 3.8 | 3.8 | -1.4 |

*Table 7.* Calendar days of maize and soybean by phenological phases for crop simulations for the 1961–1990 period and expected climate conditions

| Phenological phase | Maize (calendar days) | Soybean (calendar days) |
|--------------------|-----------------------|-------------------------|
| To emergence | 9 | 10 |
| Maximum canopy cover | 44 | 73 |
| Maximum rooting depth | 85 | 93 |
| Start of canopy senescence | 104 | 104 |
| Maturity | 152 | 137 |
| Start of flowering | 82 | 56 |
| Length building up HI | 70 | 82 |
| Duration of flowering | 20 | 46 |

# 3. Results

## 3.1. Past and future climate conditions

In the 1961–1990 period, the observed data were analyzed: air temperature and precipitation in the growing season AS (from April to September) and the drought period JJA (from June to August) (*Table 8*). The temperature was 19.1 °C in the AS period and 20.3 °C in the JJA period, while the precipitation

was 290.7 mm for the growing season and 211.2 mm for JJA period (*Table 8*). For future conditions, the absolute change in temperature and relative change in precipitation was calculated for the 2041–2070 and 2071–2100 periods under two scenarios (A1B, A2) in compare to 1961–1990 (*Table 9*). In future conditions, rise in temperature in both periods under two scenarios is expected. There was no significant difference between the two scenarios from 0.3 to 0.5 ºC. In the AS period, the expected increase in temperature for the 2041–2070 period is 2.8 ºC (A1B) and for 2071–2100 is 4.6 ºC (A2). In the JJA drought period, the expected increase in temperature is 2.9 ºC (A1B) in 2041–2070 and 5.0 °C (A2) in 2071– 2100 (Table 9). The analyzed precipitation amount showed a significant decrease in future conditions compared to the past climate data of the period 1961–1990. In a comparison of the two scenarios, the A1B scenario showed lower precipitation for future conditions, especially for the 2041–2070. In AS period, for 2041–2070, lower precipitation by 28.2% (A1B) and 16.5% (A2) is expected. In the 2071–2100 period, more decrease in precipitation is expected, by 34.8% (A1B) and 33.7% (A2) in AS compared to 1961–1990. During JJA summer months, a considerable decrease in precipitation is expected as well. In the 2041–2070 period, the expected reduction in precipitation is 35.2% (A1B) and 25.8% (A2). Furthermore, for the 2071–2100 period, 43.55% (A1B) and 43.4% (A2) reduction is expected compared to the 1961–1990 period (*Table 9*).

*Table 8*. Climate conditions for the 1961–1990 period at Osijek location (t - temperature; p - precipitation)

|  | April-September | | June-July-August | |
| --- | --- | --- | --- | --- |
|  | t (ºC) | p (mm) | t (ºC) | p (mm) |
| 1961–1990 | 19.1 | 290.7 | 20.3 | 211.2 |

*Table 9*. Absolute change in temperature (°C) and relative change in precipitation (%) for 2041–2070 and 2071–2100 using ECHAM model under A1B and A2 scenarios (t - temperature; p - precipitation)

|  | A1B | | | | A2 | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | April- September | | June-July-August | | April- September | | June-July-August | |
|  | t (°C) | p (%) | t (°C) | p (%) | t (°C) | p (%) | t (°C) | p (%) |
| 2041–2070 | 2.8 | -28.2 | 2.9 | -35.2 | 2.3 | -16.5 | 2.4 | -25.8 |
| 2071–2100 | 4.3 | -34.8 | 4.5 | -43.5 | 4.6 | -33.7 | 5.0 | -43.4 |

## 3.2. Climate change impact on maize and soybean yields, net irrigation, WUE, and IWUE

In past climate conditions (1961–1990), the simulated maize yield in non-irrigated conditions was as usual in real conditions, about 7.3 dm t ha$^{-1}$, and 7.1 dm t ha$^{-1}$ in irrigated conditions (*Tables 10* and *11*). For the same period of time, the *WUE* ranged from 1.32 kg m$^3$ in non-irrigated to 1.28 kg m$^3$ in irrigated conditions. As for *IWUE*, net irrigation (40 mm) reduced the maize yield for 3.53 kg mm$^{-1}$. According to the analyzed yield results, in future conditions it is expected a little lower or the same yield in non-irrigated maize production, and higher yield values when the maize is under irrigated conditions (*Tables 10* and *11*). In the 2041–2070 period, in non-irrigated conditions, the maize should have 0.4 dm t ha$^{-1}$ lower (A1B) or 0.2 dm t ha$^{-1}$ (A2) higher yield. During the same period, the *WUE* for non-irrigated conditions for A1B scenario is 1.14 kg m$^3$ and 1.28 kg m$^3$ for A2 scenario. In the further period, till 2100, it is expected that the yield slightly decrease from 0.6% (A1B) to 0.3% (A2) compared to the 1961–1990 period. Furthermore, the *WUE* for this period is 1.07 kg m$^3$ for A1B and 1.11 kg m$^3$ for A2 scenario (*Table 10*). In irrigated conditions, maize production showed an increase in yield from 1.0 dm t ha$^{-1}$ in 2041–2070 and 1.4 dm t ha$^{-1}$ in 2071–2100. There were no significant differences between the results of the two scenarios. In irrigated conditions, it is important to mention that the net irrigation is expected to increase in both periods. In 2041–2070, the absolute change in net irrigation was 74.8 mm (A1B) and 38.3 mm (A2). For 2041–2070, the *WUE* is 1.34 kg m$^3$ and *IWUE* is 11.8 kg mm for A1B scenario while for the A2 scenario *WUE* is 1.37 kg m$^3$ and *IWUE* is 7.64 kg m$^3$ (*Table 11*). In 2071–2100, further increase in net irrigation up to 80.7 mm under A2 scenario is expected. For this period, *WUE* is 1.33 kg m$^3$ for both scenarios, while *IWUE* is 14.01 kg mm for A1B and 12.16 kg mm for A2 scenario. In soybean production, the crop simulations for the 1961–1990 period showed, that soybean yield was similar to real yield produced in Croatia, 2.9 dm t ha$^{-1}$ in non-irrigated conditions and 3.2 dm t ha$^{-1}$ in irrigated conditions (*Tables 12* and *13*). As for *WUE*, it ranges from 0.56 kg m$^3$ in non-irrigated to 0.60 kg m$^3$ in irrigated soybean production, while the *IWUE* was 1.9 kg mm. In future conditions, in both periods yield increase is expected. In 2041–2070, in non-irrigated production, the expected increase is from 0.7 (A1B) to 0.9 dm t ha$^{-1}$ (A2) in soybean yield, while the larger increase is expected in the period 2071–2100, for 0.9 dm t ha$^{-1}$ under A1B scenario and 1.1 dm t ha$^{-1}$ under A2 scenario. The *WUE*, for the mentioned period, ranged from 0.61 to 0.68 kg m$^3$ for A1B and A2 scenarios for 2041–2070, and from 0.63 to 0.66 kg m$^3$ in 2071–2100 (*Table 12*). The rise in soybean yield in irrigated conditions is also noticeable, 1.3 (A1B) and 1.8 dm t ha$^{-1}$ (A2) in the 2041–2070 period and 1.3 (A1B) to 1.9 dm t ha$^{-1}$ (A2) in the 2071–2100 period. There was no significant difference between the scenario results. In irrigated soybean production for that period

*WUE* is 0.6 kg m³, while *IWUE* is 1.9 kg mm (*Table 13*). In irrigated production, the net irrigation was significantly higher in both periods, than in the 1961–1990 period. The absolute change in net irrigation is expected to be 82.9 (A1B) and 46.3 mm (A2) in the 2041–2070 period and 103.5 (A1B) 93.3 mm (A2) in the 2071–2100 period. The *WUE* for the 2041–2070 period ranges from 0.78 to 0.80 kg m³ for A1B and A2 scenarios. Furthermore, for the 2071–2100 period it ranges from 0.82 to 0.85 kg m³. As for *IWUE* for the 2041–2070 period, it ranges from 4.89 to 4.27 kg mm for A1B and A2 scenarios, while for the 2071–2100 period it ranges from 5.39 to 5.56 kg mm for A1B and A2 scenarios (*Table 13*).

*Table 10.* Average yield (dm t/ha) and water use efficiency (*WUE*, kg/m³) for non-irrigated maize crop in 1961–1990 and future conditions under A1B and A2 SRES scenarios

| Period | | Yield (dmt/ha) | Precipitation (mm) | ETo (mm) | WUE (kg/m³) |
|---|---|---|---|---|---|
| 1961–1990 | | 7.3 | 313 | 551 | 1.32 |
| 2041–2070 | A1B | 6.9 | 220 | 607 | 1.14 |
| | A2 | 7.5 | 205 | 629 | 1.28 |
| 2071–2100 | A1B | 6.7 | 260 | 591 | 1.07 |
| | A2 | 7.0 | 206 | 637 | 1.11 |

A1B; A2 = scenarios, *WUE* = water use efficiency

*Table 11.* Average yield (dm t/ha), water use efficiency (*WUE*, kg/m³) and irrigation water use efficiency (*IWUE*, kg/mm) for irrigated maize crop in 1961-1990 and future conditions under A1B and A2 SRES scenarios

| | | Yield (dmt/ha) | Net irrigation (mm) | Precipitation (mm) | ETo (mm) | WUE (kg/m³) | IWUE (kg/mm) |
|---|---|---|---|---|---|---|---|
| 1961–1990 | | 7.1 | 40 | 313 | 554 | 1.28 | -3.53 |
| 2041–2070 | A1B | 8.2 | 110 | 220 | 609 | 1.34 | 11.8 |
| | A2 | 8.1 | 75 | 262 | 594 | 1.37 | 7.64 |
| 2071–2100 | A1B | 8.4 | 120 | 205 | 631 | 1.33 | 14.01 |
| | A2 | 8.5 | 120 | 206 | 640 | 1.33 | 12.16 |

A1B; A2 = scenarios; *WUE* = water use efficiency; *IWUE* = irrigation water use efficiency

Table 12. Average yield (dm t ha$^{-1}$) and water use efficiency (WUE, kg m$^3$) for non-irrigated soybean crop in 1961–1990 and future conditions under A1B and A2 SRES scenarios

| Period | | Yield (dmt/ha) | Precipitation (mm) | ETo (mm) | WUE (kg/m$^3$) |
|---|---|---|---|---|---|
| 1961–1990 | | 2.9 | 291 | 524 | 0.56 |
| 2041–2070 | A1B | 3.6 | 209 | 580 | 0.61 |
| | A2 | 3.8 | 243 | 564 | 0.68 |
| 2071–2100 | A1B | 3.8 | 190 | 602 | 0.63 |
| | A2 | 4.0 | 193 | 608 | 0.66 |

A1B; A2 = scenarios, *WUE* = water use efficiency

Table 13. Average yield (dm t/ha) and water use efficiency (*WUE*, kg/m$^3$) and irrigation water use efficiency (*IWUE*, kg/mm) for irrigated soybean crop in 1961–1990 and future conditions under A1B and A2 SRES scenarios

| | | Yield (t/ha) | Net irrigation (mm) | Precipitation (mm) | ETo (mm) | WUE (kg/m$^3$) | IWUE (kg/mm) |
|---|---|---|---|---|---|---|---|
| 1961–1990 | | 3.2 | 110 | 291 | 524 | 0.60 | 1.90 |
| 2041–2070 | A1B | 4.5 | 190 | 209 | 580 | 0.78 | 4.89 |
| | A2 | 4.5 | 155 | 243 | 564 | 0.80 | 4.24 |
| 2071–2100 | A1B | 5.0 | 210 | 190 | 602 | 0.82 | 5.39 |
| | A2 | 5.1 | 200 | 193 | 608 | 0.85 | 5.56 |

A1B; A2 = scenarios; WUE = water use efficiency; IWUE = irrigation water use efficiency

## 4. Discussion

### 4.1. Climate and production of maize and soybean in the 1961–1990 period

The climate data from the 30-year-long period of 1961–1990 were observed and two main agro climatic indices, temperature and precipitation were analyzed. The mean temperature was 19.1 ºC for the growing season and 20.3 ºC for the drought sensitive period. That were optimal conditions for maize and soybean vegetative and generative growths (*Miladinović et al*., 2008). The agro-climatic index, which mostly affects crop growth in interaction with air temperature and has direct impact on yield is precipitation. The observed precipitation for the

growing season was 290.7 mm. In the medium season, maize and soybean 0 to 1 variety, in our moderate continental climate under gleysol conditions has a water demand of 250–300 and 520–1000 mm for the growing season (*Komljenović* and *Todorović,* 1998; *Miladinović et al.*, 2008). In the drought sensitive period (JJA), when the temperature is the highest during the season, the optimal soil moisture is necessary for field crops. The observed precipitation in this period was 211.2 mm. The lack or excessive amount of rainfall (2010 and 2014) accompanied with high temperatures have negative impact on crop growth and yield. In such years, the irrigation is necessary, as an adaptation measure. The observed climate data for the 1961–1990 period was described as moderate continental climate, under hypogley soil type, gave an optimal condition for maize and soybean growth and yield.

## 4.2. Climate change impact on yield for the 2041–2070 and 2071–2100 periods

In future conditions, higher air temperature from 2.3 ºC in 2041–2070 and up to 4.6 ºC in 2071–2100 is expected for the growing season. The reduction in precipitation was also noted during the growing season from 16.5 to 34.8%, and lower values are expected during the summer months (JJA) from 25.8 to 43.5%. Such changes in climate were also predicted for this region by *Vučetić* (2011) and for Eastern Europe by CECILIA (2006). As for Eastern Europe conditions, *Rolbiecki et al.* (2017) have stated that for the region of northern Poland during the 2021–2050 period, the increase of water needs of the forest nurseries from 12 to 15% is expected. Authors have compared the mentioned period to the reference years of 1981–2010 and stated, that the water needs of nurseries in future climate conditions will rise in the growing period (April-September) from 427 to 489 mm on clay and from 498 to 560 mm on sandy soil. Higher air temperatures, accompanied with lower precipitation and lack of soil moisture mainly causes crop yield decrease (*Prasad* and *Staggenborg*, 2008). In the paper, in non-irrigated maize production slightly lower yield is expected under the A1B scenario and no change in yield under the A2 scenario. The yield predictions in maize production for Eastern Europe showed yield decrease from 10 to 24% on chernozem and cambisol soils under climate change. In irrigated maize production in this paper, analyses showed the possible increase in yield under climate change in both climate periods and scenarios. The higher yield is expected due to an adequate irrigation sprinkler method with higher net irrigation of 80 mm, or as two additional irrigation treatments (40 mm) than in 1961–1990. Under climate change, in non-irrigated soybean production rise in yield from 0.7 to 1.1 dm t ha^{-1} is expected, and in irrigated conditions, the expected rise is from 1.3 to 1.9 dm t ha^{-1}. This increase in yield together with a very reasonable increase in $CO_2$ concentration are also expected in the Eastern Europe predictions (CECILIA, 2006). Soybean is a C3 crop with high potential in yield increase under higher level of $CO_2$ concertation (*Southworth et al.*, 2002; *Wittwer*, 1995). The primary

reason is that increased concentration of atmospheric $CO_2$ will reduce photorespiratory losses of carbon in the C3 plant, thereby enhancing plant growth and productivity (*Allen et al.*, 1988). It has been reported that soybean yield will rise by 30% under the predicted 555 ppm $CO_2$ concentration in Illinois, assuming that soybean is well-watered and not facing nutrient stress (*Southworth et al.*, 2002). In irrigated conditions, a rise in net irrigation up to 100 mm to 2100 is expected, which means that three-times more than in 1961–1990.

### 4.3. *Climate change impact on WUE and IWUE for the 2041–2070 and 2071–2100 periods*

In average, the *WUE* for maize crop in non-irrigated conditions was the highest in the 1961–1990 period and has a trend to decrease in the future climate scenarios. This is in accordance with the results of *Kang et al.* (2015). Authors have stated that water use indices of maize under non-irrigated conditions will decrease, while the evapotranspiration efficiency, crop water use efficiency, and total water use efficiency will be larger in future conditions. In our study, the highest *WUE* is in periods with the lowest precipitation amount. In scenarios and period comparison, there are no considerable differences in the *WUE* value in the study. As for *IWUE*, it is noticeable that irrigation reduced maize yield during the 1961–1990 period. During the 2041–2070 period, considerably higher *IWUE* is expected in the A1B scenario, the scenario with a lower amount of precipitation, compared to the A2 scenario. In further period, there is no considerable differences between the *IWUE* values. The overall *WUE* in non-irrigated maize production, under climate change, is expected to decrease compared to the 1961–1990 period. On the other hand, in irrigated conditions, under climate change, higher *WUE* and *IWUE* values are expected as well, which is in accordance with a previous research of *Kang et al.* (2015). The lowest *WUE* in non-irrigated soybean production is in the 1961–1990 period, when the lowest precipitation was observed, compared to the future climate conditions. As the precipitation is expected to decrease, especially after year 2041 and further, the *WUE* will be increased under both scenarios and periods. In a comparison of two scenarios, higher *WUE* is noticed under the A2 scenario. For the 2041–2070 period, the higher *IWUE* is in scenario A1B, with lower rainfall amount and higher net irrigation. In future climate conditions, in both periods and scenarios, increase in *WUE* and *IWUE* is expected. Generally, according to the results of our study, the higher I*WUE* in future climate scenarios could be a result of the yield increase. *Deihimfard et al.* (2018) also claim, that besides the yield increase, in future climate conditions the improved *WUE* is the result of the decreased evapotranspiration, yet in our study this is not the case. According to the results of our study, in the future climate, the $ET_0$ increase is noticeable as well.

## *5. Conclusions*

Detailed analyses of climate and model results showed that

- − Possible higher air temperature up to 5 ºC, accompanied with significantly lower precipitation up to 43.5% are expected, especially during summer months in future conditions.

- − In maize production, in non-irrigated conditions, slightly lower or no change in yield, while in irrigated conditions higher yield up to 1.4 dm t ha$^{-1}$ with 80 mm higher net irrigation, or two extra irrigation treatments per growing season are expected.

- − In non-irrigated maize production, *WUE* is expected to decrease while no change in irrigated production will occure.

- − The I*WUE* results showed very significant increase trend in the future climate.

- − In non-irrigated soybean production, higher yield up to 1.1 dm t ha$^{-1}$, while in irrigated conditions 1.9 dm t ha$^{-1}$ increase in yield are expected in the future conditions. In irrigated conditions, net irrigation is expected to be 90 mm higher, or three extra irrigation treatments will be needed compared to the 1961–1990 period.

- − In soybean production, a slight increase in *WUE* under both non-irrigated and irrigated conditions is expected.

- − In irrigated conditions, the I*WUE* results showed very significant increase in the future conditions.

Based on the analyses, a possible benefit for both crops is observed under climate change in non-irrigated and irrigated conditions as well. In maize production, the benefit is expected only under irrigated conditions, due to crop efficiency in irrigation and very significant increase in *IWUE*, while the increase in soybean yield is expected in both non-irrigated and irrigated conditions. The simulated higher yield is due to the expected increase in the $CO_2$ concentration in the future climate. Soybean is a C3 plant, which is more sensitive to higher $CO_2$ concentrations than C4 plants (maize, sorghum, millet), which can greatly benefit productivity. The increase in *WUE,* and especially *IWUE,* in soybean production is due to the expected increase in yield. The analyzed yield, net irrigation, and *IWUE* results showed potential prosperity in irrigated conditions under climate change. This could classify Osijek-Baranja County as priority area for further irrigation action plans. Some small-scale irrigation programs introduced by the government could assist the sustainable crop production in the study area.

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