SZENT ISTVÁN
UNIVERSITY

PRECISION IRRIGATION TECHNOLOGY: APPLICATION OF THE MODEL AQUACROP IN PROCESSING TOMATO GROWING

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Introduction, goals of the research

Low amount and unfavourable distribution of precipitation caused problems to farmers in many years (Jolánkai et al., 2018, Szalai, 2009). The uncertainty caused by the climate can be eased with irrigation, although, there are other solutions as well (Birkás et al., 2008). The volume of irrigation was around 100.000 ha in Hungary in the past decade. The fluctuation depends on the season type.

Site-specific irrigation contributes to the water- and energy savings and has a positive effect on plant's water productivity and the environment (Evans et. al., 2013). Besides low water supply, there are negative effects of overirrigation as well such as, deep percolation, surface run-off and concentration (Fiebig and Dodd, 2016). The irrigation machines that are capable of site-specific irrigation are not common in Central-Europe. Shaping the areas of differently irrigated polygons is possible on prescription maps. There is only few information about the transition between adjacent, differently irrigated zones and the uniformity of water distribution in these VRI zones. The establishment of prescription map can be based on various factors characterizing the fields (e.g. infiltration, relief, water holding capacity etc.). There is no reason for detailed maps if the machine is not capable of following the prescription map. Moreover, it is important to sample plants from spots where the desired amount of water was irrigated by scientific plant irrigation experiments. The examination of under- and overirrigated areas and volumes is neglected by measuring water distribution uniformity.

There are growth models, that are capable of simulate the effect of irrigation to plants. A good model can be part of the decision support system of growers. AquaCrop is a crop growth model developed by FAO for simulating the interaction between soil-plant-atmosphere (Steduto et al., 2012). AquaCrop has several inbuilt data required for simulation, however, site- and plant specific calibration and validation contribute to improve accuracy and usability (Karunaratne et al., 2011). The model can consider different stress factors by simulation (air temperature, soil salinity, water scarcity). Water scarcity induce stomatal closure in plants and affect biomass production through reducing transpiration. This stress indicator was not examined thoroughly in studies until now, so the comparison of values measured in tomato with different water supply and the modelled values is relevant.

Tomato is one of the most important horticultural plants and successful growing is possible only when irrigation is provided. Therefore, information about its reaction to irrigation is essential. In the case of water deficit plant's biomass and yield production is reduced, but its application in an adequate level is an opportunity for improving fruit quality of processing tomato (Pék et al., 2017). The adequate level of soluble solids content in processing tomato fruit concerns growers, processing industry and scientists as well. Deficit irrigation reduces the potential biomass and yield, but the improved quality and water savings can be more beneficial (Patané et al., 2011), besides, we can maximize plant productivity per unit water (Fereres and Soriano, 2007).

I answered the following questions in my research:

- What will be the effect of different water supply levels provided by sprinkler irrigation to the yields and soluble solids content of processing tomato?
- What water stress levels will occur in tomato under different water supplies?
- Which measuring device (Thermal cam or remote infrared thermometer) and which water stress index (CWSI or SDD) will be more feasible for monitoring water stress in processing tomato?
- How accurately can the model AquaCrop estimate the dry yield of biomass and fruit?

- How accurately follows the AquaCrop model the stress levels in tomato induced by water shortage?
- Is the precision centre pivot feasible for conducting deficit irrigation experiments using variable rate irrigation, considering transition between zones and water distribution uniformity?

Materials and methods

Deficit irrigation experiment

Open field experiments were conducted in Szarvas, on the experimental field of Szent István University in 2017 and 2018. UG812J F1 hybrid was used for the experiment. Three different water supply levels in 2017 and four water supply levels in 2018 were provided to the plants. Irrigation was provided with a precision centre pivot equipped with VRI iS system in the differently irrigated parcels. The different water supply rates based on potential evapotranspiration (PET) computed by AquaCrop. Optimal water supply received 100% of PET, moderately stressed plants received 50% of PET and a severely stressed parcel was not irrigated regularly. Mild water stress was represented by a parcel that received 75% of PET only in 2018.

In the end of the growing season I examined the relationship between data of yield quantity, soluble solids content, soluble solids yield and water supply levels, moreover, I computed the water use efficiency as well.

Monitoring water stress in processing tomato

I monitored the different levels of water stress via measuring leaf surface temperatures in the plants grow under different level of water supply. I used two different measuring devices for the measurements: a remote infrared thermometer and a thermal cam attachable to a smartphone. I computed two different indices from the data: stress degree day (SDD) and crop water stress index (CWSI). I examined which device is more feasible to monitor water stress and which index results in a more detailed picture off the water stress levels in processing tomato.

Measuring water distribution uniformity, under- and overirrigation

To measure the water distribution uniformity, I conducted two different types of measurements: grid shape measurements and one according to the standard of ASAE. I computed Christiansen-uniformity (CU_C) and distribution uniformity (DU) form the data gathered in the grid shape measurements. For the other type, I placed the rain gauges radially to the pivot centre and computed Heerman and Hein-uniformity (CU_{HH}) from the data.

For the examination of under- and overirrigation I used the data of the grid shape measurements. I made 3D surfaces according to the measured water depth and I used modified Shepard interpolation for these. I subtracted the flats representing the desired water depth from the 3D surfaces and got the areas and volumes of over- and underirrigation as a result. I converted the results to hectare scale.

AquaCrop model

The plant growth model AquaCrop can simulate the biomass, fruit yield and water stress, thus, I compared my results from the open-field experiment to the modelled values to examine the usability in processing tomato. I only compared the biomass, fruit yield and water stress values (Ststo) in 2017. In 2018 I monitored the biomass growth during the season too. For this, I collected samples 6 times in the season from the parcels with different level of water supplies.

Data processing, statistics

For the graphs and diagrams and statistical tests, I used R 3.4.3 (R Core Team, 2018), Rcommander package (Fox and Bouchet-Valat, 2017) and Microsoft Excel. I checked the normality of the data using Shapiro-Wilk test, and the homoscedasticity using Bartlett-test. I used ANOVA and Tukey post-hoc test to reveal the effect of treatments. I also used Pearson-correlation and linear regression to analyse the relationship of the data. I used mean absolute error (MAE) and root mean squared error (RMSE) to evaluate the accuracy of models.

Results

Yields

The 3 different water supply levels were 186 (K), 319 (I50) and 453 mm (I100) in 2017. In the second year, 171, 258, 297 and 340 mm were the total water supply in the K, I50, I75 and I100 treatments respectively. The least marketable yield was found in 2017 in the K treatment (42.4 t ha^{-1}) during the two years of experimenting and the highest in the I100 treatment (103,7 t ha^{-1}) in the same year. The lowest °Brix resulted in the I100 treatment of 2018 (4,38) and highest was in the control (6,14 °Brix). Soluble solids yield did not reach 5 t ha^{-1} during the two years in any treatment. There was no significant difference between treatment when water use efficiency was compared. Analysing the data of the two years, the results showed that water supply had significant effect on marketable yields (R^2=0.89), soluble solids content (R^2=0.73) and soluble solids yield (R^2=0.93) as well.

Leaf surface temperature measurements

SDD values computed from remote infrared thermometer data and CWSI values computed from thermal cam data differentiated all three treatments in 2017. In 2018, there were 4 instead of 3 treatments, so the segregation of treatments was harder. The best results were given by the CWSI computed from thermal cam data but distinguishing the mildly stressed treatment from the moderately and non-stressed treatments was not possible. The highest cumulated SDD and CWSI were reached in K treatment in 2017 while the lowest values were found in the I100 treatment of 2017. Considering the results of the two years, the water supply showed strong effect to the cumulated CWSI (R^2=0.95). The cumulated CWSI affected significantly the marketable yield (R^2=0,92).

Uniformity of irrigation, transition zones, under- and overirrigation

Uniformity was excellent by every measurement. CUC was 91.8-92.9% in the 100% rate zone and 88.8-90.8% in the 50% rate zone. The values of DU was 88.7-90% and 85.1-86.7% in the 100% and 50% rate zones respectively. CU_{HH} uniformity was above 90% in the I100 treatment in every case and between 97.8 and 92.4% in the I50 parcel. The width of transition was differing according to the placement of the measuring line (perpendicular or parallel to longer side of the field). We must consider 9-10 m wide transition between zones if we want to achieve good uniformity and close water depth to the desired.

The highest overirrigated volume in the I100 parcel was 15.8 m^3 ha^{-1} and the lowest 6.1 m^3 ha^{-1}. The highest and lowest underirrigated volume was 11.8 and 1.1 m^3 ha^{-1} respectively. Highest and lowest overirrigated volumes were 6.7 and 4.1 m^3 ha^{-1} and underirrigated volumes were 5.2 and 0.1 m^3 ha^{-1} in the 50% rate zone.

AquaCrop

The best relationship of the modelled and measured biomass growth data was found under optimal water supply (r=0.99) and it is weakening together with reducing water supply. The reason for this is the overestimated biomass yields in the deficit irrigated treatments. Good results in control could be achieved when I reduced the reference canopy cover. Analysing the two-year data, strong correlation was found between modelled and measured yields (r=0.89). The modelled water stress showed moderate correlation with CWSI (computed from measured data). The correlation was r=0.60 and r=0.50 in 2017 and 2018 respectively. The cumulated modelled and measured data gave better results (r=0.90).

New scientific results

1. 4.15 t ha^{-1} soluble solids yield was reached with irrigation of 75% of potential evapotranspiration calculated by AquaCrop which did not differ significantly from the soluble solids yield of the optimal water supply but 25% (~44 mm) irrigation water saving was realised compared to the optimal water supply level.
2. CWSI was more feasible for water stress monitoring in processing tomato than SDD. CWSI provided more detailed resolution considering the two years. The thermal camera (160×120 pixel resolution, 8-14 μm) was better than the infrared remote thermometer. I recommend the combination of CWSI and thermal camera for monitoring water stress in processing tomato.
3. The cumulated CWSI values showed significant relationship with the production parameters of processing tomato. There is strong relationship between cumulated CWSI and marketable yield (R^2=0,91). The higher the stress the higher the °Brix was (R^2=0,79), resulting in lower soluble solids yield per hectare (R^2=0,92).
4. AquaCrop provided good estimations in the case of biomass and fruit yield under optimal water supply and severe water stress after some modifications (reference canopy cover and harvest index).
5. Stress values induced by water depletion simulated by AquaCrop were comparable only in control.

   The cumulated stress values of the monitored period were in significant relationship with the cumulated stress values simulated by the model considering every water supply level. I state that the model provides less good results in daily stress estimation, however, the relationship of cumulated modelled stress values of the whole growing period and production parameters is convincing (r= -0,84- -0,91).

Conclusions and recommendations

Effect of different water supply levels to yields and soluble solids of processing tomato

Increasing water supply resulted in step-wise growth of biomass and fruit total and marketable yield as it was proven by numerous other studies (Giuliani et al., 2016; Patané et al., 2011, 2014). Also, many studies found that when we increase water supply, we find decreasing soluble solids content (Helyes et al., 2014; Kuşçu et al., 2014; Pék et al., 2015; Zhang et al., 2017). These indicators reacted consistently to water supply levels in the two years. The original goal of deficit irrigation that the increased quality and realised water saving balance the reduced fresh weight yield fulfilled best in the I75 treatment in 2018. There was not significant difference in soluble solids yield between I100 and I75 treatments. Thus, I suggest that irrigation water amount should be the 75% of PET estimated by AquaCrop on clay-loam soil to maximize soluble solids yield and realize water saving compared to the plant's optimal water supply (Nangare et al. (Nangare et al., 2016; Patané and Cosentino, 2010). I did not find any significant difference between treatments in the case of WUE. The means were close to each other in the first year of experimenting, however, in the second year there was difference between the I100 and the K and the similar I50 water supply levels, since the WUE of I100 was higher. Although, I concluded that the water productivity was consistent on every water supply level advised by statistics.

Results of water stress measurements

The K, I50 and I100 treatments were separated by ANOVA looking at water stress levels in both years. In the first year, the SDD values computed from infrared thermometer data and CWSI values computed from thermal cam data showed good results, because all three water supply levels were distinguishable with respect to means and cumulated values as well (Nardella et al., 2008). In 2018 I could not differentiate all four water supply treatments by means. CWSI computed from thermal cam data gave the best results with which only the I75 was not distinguishable from the adjacent water supply levels by the means and the cumulated values of I75 and I50 were also close. Hence, I concluded that for water stress monitoring of this processing tomato hybrid the CWSI computed from thermal cam data was the best option. Linear regressions revealed strong effect of cumulated CWSI to both marketable yield and soluble solids yield (Sezen et al., 2014). Thus, the combination of the relatively easily computable CWSI and an inexpensive thermal cam attachable to smartphone can be a good option to monitor the water stress in plants under different water supply or to plan irrigation schedule (Gerhards et al., 2016; Ihuoma and Madramootoo, 2017; Jones, 2004). Moreover, I suggest expanding the research to spatial applicability (Berni et al., 2009; Meron et al., 2010) which is possible by involving UAV-s.

Water distribution uniformity of the centre pivot and transition between zones

The irrigation machine showed proper uniformity by every measurement in VRI zones with different rates (Dukes and Perry, 2006; Irmak et al., 2011; Yari et al., 2017). The evaluation of this was very important considering the experiments since a scientific irrigation experiment requires uniform water application with precise water amounts. According to results these requirements were fulfilled. The under- and overirrigation was not significant suggested by the results of the water distribution models. The measurements showed that ca. 9-10 m transition must be considered by the adjacent parcels irrigated with different rates if precise water application is essential (Takács et al., 2018). Similar or less transition was published in other studies (O’Shaughnessy et al., 2013; Zhao et al., 2014). If we survey several properties of the field that are relevant for shaping VRI zones for irrigation, then this information about transition can also be considered when we plan the spatial resolution of surveying.

Evaluation of AquaCrop simulations

Following biomass growth during the growing season was matching in the case of optimal water supply and severe water stress (Paredes et al., 2015). Great inaccuracies in calculation occurred in the deficit irrigation treatments during and at the end of the season (Ahmadi et al., 2015; Greaves and Wang, 2016) which suggested the overestimation of the model (Katerji et al., 2013). Mid-season inaccuracies are partly explainable with the low sample size taken during the season. By setting the reference harvest index according to the experimental data, there was good correlation between modelled and measured fruit yield. The daily resolution of modelled stress values induced by water depletion in soil are not sophisticated enough, thus, proper comparison was not possible in the irrigated parcels, since the model barely calculated any stress even in the deficit irrigated parcels. Moderately strong correlation was found between modelled stress values and CWSI values that are based on measured data. As there was overestimation in fruit yield in deficit irrigated parcels, these results suggested that the model underestimated the water stress in these parcels. Despite, I found good correlation between cumulated stress values and some indicator of processing tomato production, so, in relation to each other the stress simulation was good, but the scale proved to be low.

The evaluation of the model must be continued and collecting more data for calibration and validation is necessary which will increase accuracy prospectively (Mohammadi et al., 2016; Paredes et al., 2014; Salemi et al., 2011). For this, even remote sensing data can be usable (Trombetta et al., 2016). The most important is that the effect of water supply to fruit yield to be more accurate to reveal better the potential results of deficit irrigation.

Publications related to field of research

International, impact factor journal:

1. **Takács, S.**, Bíró, T., Helyes, L., Pék, Z.: 2018. Variable Rate Precision Irrigation Technology for Deficit Irrigation of Processing Tomato. Irrigation and Drainage. online.
2. Le, A. T., Pék, Z., **Takács, S.,** Neményi, A., Daood, H. G., Helyes, L.: 2018. The Effect of Plant Growth Promoting Rhizobacteria (PGPR) on the Water-Yield Relationship and Carotenoid Production of Processing Tomatoes. HortScience. 53. (6). 816-822.
3. Le, A. T., Pék, Z., **Takács, S.,** Neményi, A., Helyes, L.: 2018. The effect of plant growth promoting rhizobacteria (PGPR) on yield, water use efficiency and Brix of processing tomato. Plant, Soil and Environment. 64. 523-529.

Foreign language journals without impact factor:

1. **Takács S.**, Molnár, T., Csengeri, E., Le, A. T.: 2018. Application of AquaCrop in processing tomato growing and irrigation water demand calculation. Acta Agraria Debreceniensis. 2018/74. 183-187.
2. **Takács, S.**, Pék, Z., Bíró, T. and Helyes, L.: 2019. Heat stress detection in tomato under different irrigation treatments. Acta Horticulturae. 1233. 47-52.

Hungarian language journals without impact factor:

1. **Takács, S.**, Máthé, B., Katona, B. L., Le, A. T., Pék, Z.: 2017. Ipari paradicsom modellezése AquaCrop szoftverrel. Kertgazdaság. 49. (4) 31-38.

2. Le, A. T., **Takács, S.**, Bakr, J. A.: 2016. Vízellátás és mikrobiológiai oltás együttes hatása a paradicsom mennyiségi és minőségi paramétereire. Kertgazdaság. 48. (4). 32-39.

<u>Conference proceedings</u>:

1. **Takács, S.**: 2018. Víztakarékos öntözési módok vizsgálata. SZIE kiváló tehetségei konferencia. 2018. február 9., Gödöllő. Absztrakt kötet folyamatban.
2. **Takács, S.**, Pék, Z., Bíró, T., Helyes, L.: Heat stress detection in tomato under different irrigation treatments. XV. International Symposium on Processing Tomato – XIII. World Processing Tomato Congress: (2018. június 11-15., Görögország). Acta Horticulturae. 1233, 47-52.
3. **Takács, S.**: Vízstressz vizsgálat ipari paradicsomban. Alkalmazkodó vízgazdálkodás: Lehetőségek és kockázatok, Víztudományi nemzetközi konferencia, 2018.március 22., Szarvas. Konferencia kiadvány. 196-201.
4. **Takács, S.**, Helyes, L., Bíró, T., Pék, Z.: 2018. Irrigation water saving method using precision technology. PREGA Science. Papers presented at the 2nd Scientific Conference on Precision Agriculture and Agro-Informatics. AquaWorld Resort, Budapest. 20.02.2018. Agroinform Média Kft. Budapest. 2018. 44-45 p.
5. **Takács, S.**, Neményi, A., Szuvandzsiev, P., Hussein, D., Nagy, Zs., Korsós, M., Helyes, L., Pék, Z.: 2018. Estimation soluble solids content of sour cherry fruits using NIR spectrometer. 12th International Conference on Agrophysics: Soil, Plant & Climate. 2018. szeptember 17-19., Lublin, Lengyelország. Absztrakt kötet.

6. Mészáros, M., **Takács, S.**, Molnár, V.: 2016. Körbeforgó öntözőberendezés munkaminőségi vizsgálata. 2016. Kihívások a mai modern mezőgazdaságban. Konferencia kiadvány. 144-150.

7. Rácz, I.-né, Terbe, T., **Takács, S.**: 2016. A növények kémiai kommunikációja - Amikor a növények segítségért kiáltanak. 2016. Kihívások a mai modern mezőgazdaságban. Konferencia kiadvány. 85-90.

8. Molnár, T., **Takács, S.**, Futó, Z.: 2016. Herbicidek hatása az arbuszkuláris mikorrhiza kialakulására. 2016. Kihívások a mai modern mezőgazdaságban. Konferencia kiadvány. 81-84.