ESTIMATION OF AREAL EVAPOTRANSPIRATION IN SOYBEAN CANOPY USING THE BOWEN METHOD

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Abstract

Our studies were carried out in the summer of 2020 at the Agrometeorological Research Station of the Georgikon Campus of the Hungarian University of Agriculture and Life Sciences with a Bowen-station deployed in a soybean canopy. The meteorological parameters measured in every 10 min were as follows: within canopy air temperature and humidity, above-canopy air temperature and humidity measured at two levels, and wind speed, as well as soil temperatures measured at several levels. We also completed our measurements with weekly stand height and leaf area measurements (LAI), which are important for the model. Daily evapotranspiration (ET) was calculated from the 10-minute microclimate data. The evapotranspiration modelled with Bowen's ratio in the 2020 measurement season is a state-of-the-art procedure. A Bowen-station provides a relatively inexpensive solution for estimating the spatial evapotranspiration of field crops.

Keywords: soybean, field experimten, daily evapotranspiration, Bowen-station

Összefoglalás

Vizsgálatainkat 2020-ig nyarán a Magyar Agrár- és Élettudományi Egyetem Georgikon Campuszának Agrometeorológiai Kutatóállomásán szója állományba kihelyezett Bowen-oszloppal végeztük. A 10 percenként mért meteorológiai paraméterek: állományban mért léghőmérséklet és légnedvesség, állomány felett két szintben mért léghőmérséklet és légnedvesség, és állomány felett mért szélsebesség, valamint több szinten mért talajhőmérsékletek. Méréseinket heti rendszerességgel a modell szempontjából fontos állománymagasság és levélfelület-mérésekkel (LAI) is kiegészítettük. A 10-perces mikroklíma adatokból napi evapotranszspirációt számoltunk. A 2020-as mérési idényben Bowen-aránnyal modellezett evapotranszspiráció korszerű eljárás. Az állományba telepített állomás viszonylag olcsó megoldást jelent szántóföldi kultúrák területi evapotranszspirációjának becslésére.

Kulcsszavak: szója, szántóföldi kísérlet, napi evapotranszspiráció, Bowen-állomás

Introduction

Soya (*Glycine max* (L.)) is one of our staple crops with its continuously growing cultivation area. In Hungary, the area under soybean cultivation and the number of producers have increased significantly since 2015 due to state support. The production area has increased from 42 000 hectares to 77 000 hectares while the number of producers has reached 5 000 hectares

Evapotranspiration (ET) is one of the most important expenditure parameters of the water balance, which can only be compensated by rainfall or irrigation. A wide range of local factors can influence soybean evapotranspiration and seed yield, including farming practices, climatic and soil conditions in the study area (Payero et al., 2005) and the characteristics of the varieties sowed. Irmak (2017) showed factors affecting water requirements of soybean vary depending on canopy characteristics, plant surface cover, variety/variety group, and susceptibility to pests and diseases. All these details are variety-specific parameters. Each member of the list should be taken into account when comparing the ET results of soybean varieties of different origin. Evapotranspiration values of soybean depend on variety-specific biological traits, soil surface cover, crop maturity group and disease susceptibility (Irmak and Sharma 2015). Anda et al. (2020) investigated the effect of plant water stress on yield in modified compensatory evapotranspiration meters during the 2017 and 2018 growing seasons.

Considering the increasing crop area and climate change, the water requirements of soybeans are of primary importance to know. Our objective was to determine the evapotranspiration of soybean in the 2020 growing season in Keszthely, Hungary.

Material and method

Our experiments were carried out at the Agrometerorological Station of the Department of Meterology and Water Management of the Georgikon Faculty of the Hungarian University of Agriculture and Life Sciences (N 46°44′; E 17°14′) (Figureure 1). Two soybean varieties (Sinara and Sigalia) from Karintia Ltd. were sown in a 0.3 hectare plot of the station at a density of 40 plant/m^2.

Figureure 1. The Agrometerological Station at Keszthely, Hungary, the site of the experiments (Google Earth)

Instrumentation of the station installed in the soybean canopy: two Ta+RH sensors placed 1 and 2 meters above the plant, 2D sonic wind gauge above the plant stand at 2 m, and an integrated soil thermometer rod. Radiation was measured with a Kipp & Zonen CMP11 albedo meter (Figure 2).

Figure 2 Bowen-station and albedo meter in soybean in Keszthely, Hungary, in 2020 (G Soós)

The hourly evapotranspiration was modelled using a modified dual source Bowen method (Massman ,1992; Burba et al.,1999). The basis was the net energy balance, R_n (the difference between shortwave and longwave radiation), which is the source of the energy-intensive processes in the reed stand. From the energy balance equation:

$$R_n = G + \lambda E + H \quad (1)$$

where: H: sensible heat flux, λE: latent heat flux, G: ground heat flux.

Bowen ratio: expressed as the ratio of sensible (H) to latent heat fluxes (λE):

$$\beta = \gamma \frac{\Delta T}{\Delta e} \quad (2)$$

The latent heat flux:

$$\lambda E = \frac{R_n - G}{1 + \beta} \quad (3)$$

In our case, G is calculated from the change in soil temperature (Chung and Horton, 1987):

$$G = -\lambda\left(\frac{T_2 - T_s}{\Delta z}\right) + (T_s - T_1) * C\frac{\Delta z}{2\Delta t} \tag{4}$$

where λ: soil thermal conductivity (W m-1 °C-1), Ts: soil surface temperature (°C), T1: soil surface temperature at the previous time (°C), T2: soil temperature of layer 2 at the previous time (°C), z: soil depth (m), t: time interval (s).

The sensible heat flux (H):

$$H = \beta\frac{R_n - G}{1+\beta} \tag{5}$$

The surface energy budget is (R_{ns}):

$$R_{ns} = G + \lambda E_s + H_s \tag{6}$$

The energy budget of a given thickness of vegetation (R_{nv}):

$$R_{nv} = \lambda E_v + H_v \tag{7}$$

where: λE_v: vegetation latent heat flux, H_v: vegetation sensible heat flux.

The net radiation is the combined energy of the surface and the stand:

$$R_n = R_{ns} + R_{nv} \tag{8}$$

The sums of latent and sensible heat:

$$\lambda E = \lambda E_s + \lambda E_v \tag{9}$$

$$H = H_v + H_s \tag{10}$$

The surface net radiation is calculated from the Monsi-Saeki (1953) formula. The extinction coefficient (k) is determined using digital image processing by weighing the incident radiation by the area ratio of sunlit and shadowed spots:

$$R_{ns} = (R_n)\exp(-kLAI) \tag{11}$$

Surface Bowen ratio, (β_s) latent heat flux, and sensible heat flux are approximated as follows:

$$\beta_s = \frac{H_s}{\lambda E_s} \qquad (12)$$

$$\lambda E_s = \frac{R_{ns} - G}{1 + \beta_s} \qquad (13)$$

$$H_s = R_{ns} - G - \lambda E_s \qquad (14)$$

β_s is needed to calculate λEs, Hs, λEv and Hv. derived by Massman (1992), taking into account that in our case the resistance to surface water vapor transport is zero.

$$\beta_s = \frac{\rho_a C_p (T_{ws} - T_a) r_a^{-1}}{\left[\lambda \rho_a / (\gamma P)\right] (e_{Tws} - e_a) r_a^{-1}} \qquad (15)$$

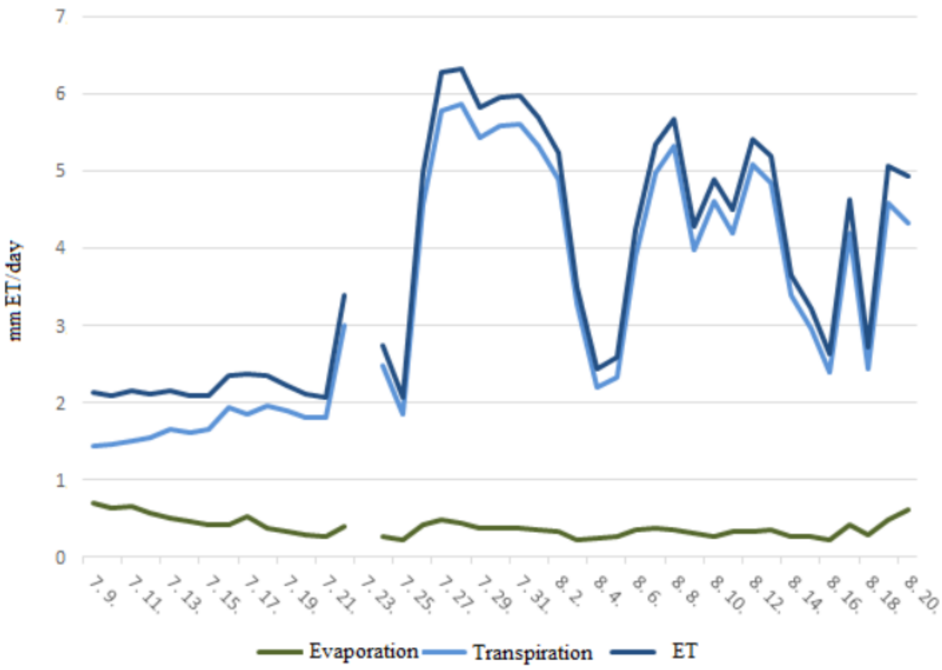
Where: ρ_a: wet air density, C_p: air heat capacity, T_{ws}: water surface temperature (measured), T_a: air temperature (measured), r_a: aerodynamic resistance,

λ: latent heat capacity of vapour, γ: psychrometric constant, P: atmospheric pressure, e_{Tws}: surface vapour pressure (measured), e_a: above-canopy vapour pressure (measured).

Data were processed in MS Excel using the statistical tool Analysis ToolPak.

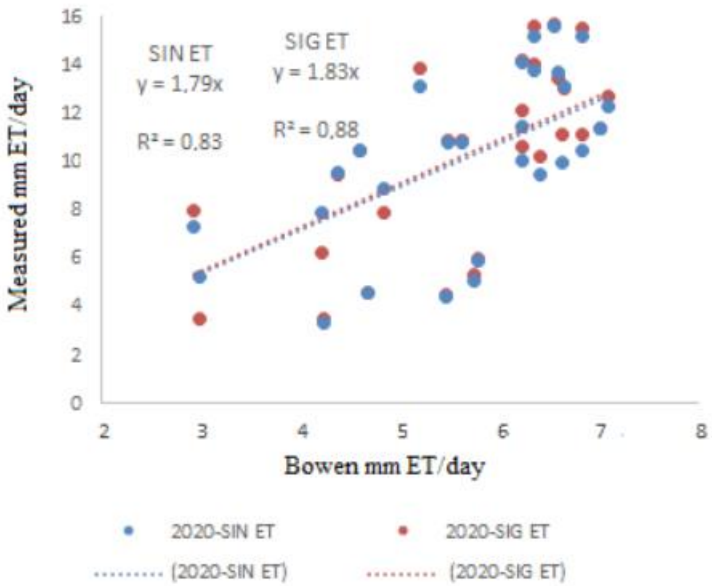
Results and discussion

Ten-minute measurements were used to produce hourly and then daily totals. The model allows the separate calculation of evaporation and transpiration. The daily evapotranspirations of mature vegetation from 7 July to 20 August 2020 are shown in Figureure 3. The low values in August can be explained by the rainy weather.



Figureure 3: Daily evapotranspiration of soybean canopy modelled with Bowen method in Keszthely, Hungary in 2020

The actual daily evapotranspiration values measured in evapotranspirometers with "ad libitum" water supply were compared with the modelled daily evapotranspiration values obtained from Bowen-station in the plot. The results are shown in Figureure 4.



Figureure 4. Correlation between daily ET measured in evapotranspirometer and modelled ET from Bowen method

Conclusions

The evapotranspiration modelled with Bowen method in the 2020 growing season is a state-of-the-art technique. A station installed in the inventory provides a relatively inexpensive tool for estimating the spatial evapotranspiration of field crops. For medium and large-scale irrigation farms, it would be an excellent option for improving the dynamic calculation of the water demand for irrigation.

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References

Anda, A., Soós, G., Menyhárt, L., Kucserka, T., Simon, B. 2020. Yield features of two soybean varieties under different water supplies and field conditions. Field Crops Research **245**. 107673. https://doi.org/10.1016/j.fcr.2019.107673

Burba, G. G., Verma, S. B., Kim, J. 1999. Surface energy fluxes of *Phragmites australis* in a prairie wetland. Agricultural and Forest Meteorology **94**. 31–51. https://doi.org/10.1016/S0168-1923(99)00007-6

INTERNET: A szója termesztéséről – gazdálkodóknak. https://portal.nebih.gov.hu/-/a-szoja-termeszteserol-gazdalkodoknak (2020.10.30, in Hungarian)

Irmak, S., Sharma, V. 2015. Large-scale and long-term trends and magnitudes in irrigated and rainfed maize and soybean water productivity: grain yield and evapotranspiration frequency, crop water use efficiency, and production functions. Transactions of the ASABE **58**(1), 103–120. https://doi.org/10.13031/trans.58.10784

Irmak, S. 2017. Evapotranspiration basics and estimating actual crop evapotranspiration from reference evapotranspiration and crop-specific coefficients. Crop, Irrig. Eng Nebraska Extension. http://extensionpublications.unl.edu/assets/pdf/g1994.pdf.

Massman, W. J. 1992. A surface energy balance method for partitioning evapotranspiration data into plant and soil components for a surface with partial canopy cover. Water Resour. Res. **28**(6), 1723–1732. https://doi.org/10.1029/92WR00217

Monsi, M., Saeki, T. 1953. Über den Lichtfaktor in den Pflanzengesellschaften und seine Bedeutung für die Stoffproduktion. Jpn. J. Bot **14**, 22–52. (In German)

Payero, J. O., Melvin, S. R., Irmak, S. 2005. Response of soybean to deficit irrigation in the semi-arid environment of West-Central Nebraska. Trans. ASAE Am. Soc. Agric. Eng. **48**, 2189–2203. https://doi.org/10.13031/2013.20105

Sang-Ok, C., Horton, R. 1987. Soil heat and water flow with a partial surface mulch. Water Resources Research **23**(12), 2175–2186. https://doi.org/10.1029/WR023i012p02175