Theses of Doctoral (PhD) dissertation

ASSESSMENT OF THE ENERGETICS AND EVAPOTRANSPIRATION OF MAIZE STANDS

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1. PRELIMINARIES AND OBJECTIVES OF THE DOCTORAL THESIS

Considering the aspects of arable farming, the region of Hajdúhát is one of the most advantageous croplands of Hungary. Its continental climate with mostly unbalanced precipitation often limits the efficiency of the production of drought sensitive crops. The high available water capacity of chernozem soils in the area may compensate for the lack of water; however, sustaining the optimal level of production requires irrigation farming technologies.

A return on high input costs of irrigation will only be realised as a result of reasonable use of water, thus, the improvement of decision support systems (DSS) and utility of precision agricultural techniques have an outstanding importance. The accurate timing and calculation of the water needs of irrigation requires profound knowledge about water cycle of the field plant stands. One of its crucial points is the exploration of the physical background of evapotranspiration, and also the systematization and evaluation of its estimation methods.

For our study, grain maize was chosen as a test plant for the reason of its considerable water requirement and its significant role in the agricultural production of the region. Our main purpose was to monitoring the climate of a selected maize stand by means of continuous and accurate measurements, and also the exploration and characterization of the physical processes playing key-role in evapotranspiration. We intended to perform overall tests on the different estimation methods and algorithms of evapotranspiration, partially on the basis of the data series measured at the Debrecen-Kismacs Agro-meteorological Observatory of the University of Debrecen – Centre for Agricultural Sciences (DE-ATK). The results of the measurements were processed by means of statistical analyses, sensitivity tests and comparative analyses.

Results were verified by complete tests with a complex irrigation DSS (IDSS). As an outcome, performance of different evapotranspiration models was evaluated, and by the exploration of opportunities for the development of the model-complex, we gathered information about the operational specialities of the system. Thus, tests were extended on the whole model-sub model system.

The main purposes of the study were the following:

- enhancement of microclimatic databases of maize stands
- constructing a sufficiently accurate and low-cost measurement system for the purpose of monitoring
- performing a comparative analysis of the methods for estimation of actual and potential evapotranspiration
- performing diagnostic tests on an operating complex decision support system for irrigation

2. RESEARCH METHODS

2.1. Climatic data and reference measurements

For the estimation of reference evapotranspiration, high resolution climatic data were provided by two weather stations with sufficiently wide measurement programme, located in the region of Hajdúság, in the vicinity of Debrecen **(Fig. 1.)**.

Figure 1. Location of the weather stations ***(Google Earth satellite composite)***

Data series of the A-type pan evaporation measurements at *Debrecen-Airport (Hungarian Meteorological Service, OMSZ)* weather station had a distinguished importance for our purposes. The *Agro-meteorological Observatory* of DE-ATK means a part of the basic synoptic network of OMSZ. The measurement programme established by the two organizations in 2008 *(Szász et al. 2011)* provided a great proportion of the climatic data needed for the analyses.

From the Airport's data series, temperature, relative humidity at 2m height, wind speed at 10 m height, precipitation and pan evaporation data were used in 10 minutes and 1 day resolution. From Debrecen-Kismacs series, temperature and relative humidity at 1 and 2 m height, wind speed at 1m, 2m and 10 m height, net radiation and precipitation data series were needed as reference for the measurements in maize stands.

2.2. Climatic measurements within maize stands

In order to estimate the actual evapotranspiration and to characterize latent and sensible heat fluxes and the changes of those within a plant stand, determination of the basic atmospheric parameters was required. Data were obtained from several layers of the above-ground and below-ground spaces of the plant stand, and the heat- and water budget of the soil-plant-air system were defined. The measurement site was selected close to the weather station to ensure comparability between climatic and plant-stand data series. The selected maize stand was located near the Agro-meteorological Observatory, on the area of the Plant-Experiment Station of the National Food Chain Safety Office (NÉBIH). Measurement points of the different experimental years were specified in a 200-250 m distance from the Observatory. Measurements were conducted for the vegetation periods (July-September) of 2010 and 2011 to specify the weather parameters mainly for fully grown maize stands.

Measurement programme within maize stands included three main parts:

Soil water content measurements

Soil water content of the study site was measured by gravimetric method *(Filep 1999)* in every 8 days on average, for 1 m depth in 0.1 m resolution.

Specific values of water capacity for the 1m deep layer of the soil of the study site are the following:

Field capacity (FC):	292 mm m^{-1}
Wilting point water content (HV):	126 mm m^{-1}
Available water content (DV):	166 mm m^{-1}

The 8 days resolution water content data series were interpolated to a daily series by the IDSS of the Food and Agriculture Organization (FAO) (*Allen et al. 1998*).

Measurements of temperature and humidity within the plant stands

Temperature and humidity profile were measured in the highest possible resolution. Continuous measurements started in July in both experimental years of 2010 and 2011, in 1 minute resolution. The data-logging system was installed in the middle part of a larger contiguous block of maize stand in order to minimize edge-effect. Fetch was set for 25-30 m at minimum, in every direction.

Measurements and observations of plant phenology

In the experimental periods phonological measurements and observations were performed. For the calculation of the photosynthetically active leaf area index (LAI [m^2 m^{-2}]), the length, width and count of individual leaves was measured, and Montgomery-formula was applied. Plant height data were used to determine the growth-curve. For the daily interpolation of plant height and LAI data series, non-linear regression was carried out by asymptotic functions *(Berzsenyi 2000, Szász 1988)*. For each ascending and descending stages of the plant growing, the best fit transformed or non-transformed variations of functions were selected among logistic, Gompertz and Richards types.

2.3. Estimation methods for potential (reference) evapotranspiration

10 of the estimation methods for potential evapotranspiration were selected for comparative statistical analysis and sensitivity analysis. The analyses were performed in two steps. First, all methods were tested on the input data from the Airport series, thus pan-evaporation ("Pan") based methods were also possible to involve. In the further part of the analyses, tests

were narrowed to only three selected methods on the basis of the Kismacs data series. These methods were the following:

Pan-evaporation based methods:

Pereira model: (*Pereira et al. 1995*) *(Per)*

FAO-56 model: (*Allen et al. 1998*) *(FAO56)*

Empirical, temperature based methods:

Blaney–Criddle-m.: (*Blaney–Criddle 1950, Doorenbos–Pruitt 1977a, Burman–Pochop 1994*) *(B&C)*

Szász-method: (*Szász 1973*) (Szász)

Empirical, radiation based methods:

Makkink–FAO-24: (*Makkink, 1957, Doorenbos–Pruitt 1977b*) *(Mak)*

Priestley–Taylor model: (Priestley*–Taylor 1972, McNaughton – Jarvis 1983*) *(P&T)*

Mass-transfer based methods:

WMO-1966: (*WMO 1966*) *(WMO66)*

Mahringer-model: (*Mahringer 1970*) *(Mah)*

Combined methods:

Penman–Monteith–FAO-56 model: (*Allen et al. 1998*) *(PMF56)*

Shuttleworth–Wallace model: (*Shuttleworth–Wallace 1985*) *(S&W)*

2.4. Estimation methods for the actual evapotranspiration

The FAO-irrigation model (IDSS) – with dual crop coefficient

Daily changes in the soil water supplies were modelled by the formulas of the irrigation- and water-cycle simulation model worked out by the FAO (*Allen et al. 1998*). The basic equation of the method is the following:

$$ET_{c\,adj} = (K_s \cdot K_{cb} + K_e) \cdot ET_0$$, where

$ET_{c,adj}$: actual evapotranspiration of the crop, K_{cb}: basal crop coefficient, K_e: soil evaporation coefficient, K_s: water stress coefficient.

Estimation of the actual evapotranspiration by the Bowen-ratio method

The method for the calculation of the actual amount of evaporated and transpired water rests on the determination of the energy- and water budget for any given plant stand:

$$R_n = \lambda E + H + G \pm A, \text{ where}$$

R_n: net radiation above the surface of the crop stand, λE: latent heat flux, H: sensible heat flux, G: soil heat flux, A: sum of the advection effects.

For the calculation of the latent and sensible heat fluxes, the Bowen-ratio method was applied (*Bowen 1926*). The Bowen-ratio (β) equals to the ratio of the temperature- and vapour-pressure gradients between two specified height levels (in our case z_1=2.5 and z_2=3.0 m, for both experimental periods). In this study, gradients and β were calculated on the basis of 1 minute resolution average values. After filtering false β-values, latent heat fluxes were calculated on hourly basis, and finally, the actual evapotranspiration ($ET_{c,BR}$) was determined.

3. MAIN STATEMENTS OF THE THESIS

3.1. Construction and improvement of a customized measurement system

A customized and automated mobile measurement system was constructed for the purpose of gathering climatic data within plant stands. Within the development process, complex tests, normalization and complete calibration of each data-logger units were a highlighted objective.

The system was designed for continuous measurements within and above an average, 2-2.5 m high maize stand, up to the height of 3.0 m. As much as 16 pieces of *Voltcraft DL-120 TH* type, mobile, shielded USB data logger unit were used. On a vertical mounting, 12 units were installed at one time, by 0.25m height steps. In accordance with the main objectives of our study, accuracy of the sensors was tested by cross-calibration and finally, normalization was performed. The purpose of the tests was to compare each data-logger units with each other and with the reference instruments, too. For reference, instruments of the OMSZ measurement programme at the Agro-meteorological Observatory were used.

3.2. Microclimate and energetics of maize stands – determination of actual evapotranspiration

Vertical profiles of latent and sensible heat in the maize stand were examined in details, and the daily changes of these parameters were characterized for typical weather patterns. The latent heat of the air is proportional to the amount of water stored in that. The ratio and the gradient of the latent and sensible heat imply the degree of drought in the plant stand.

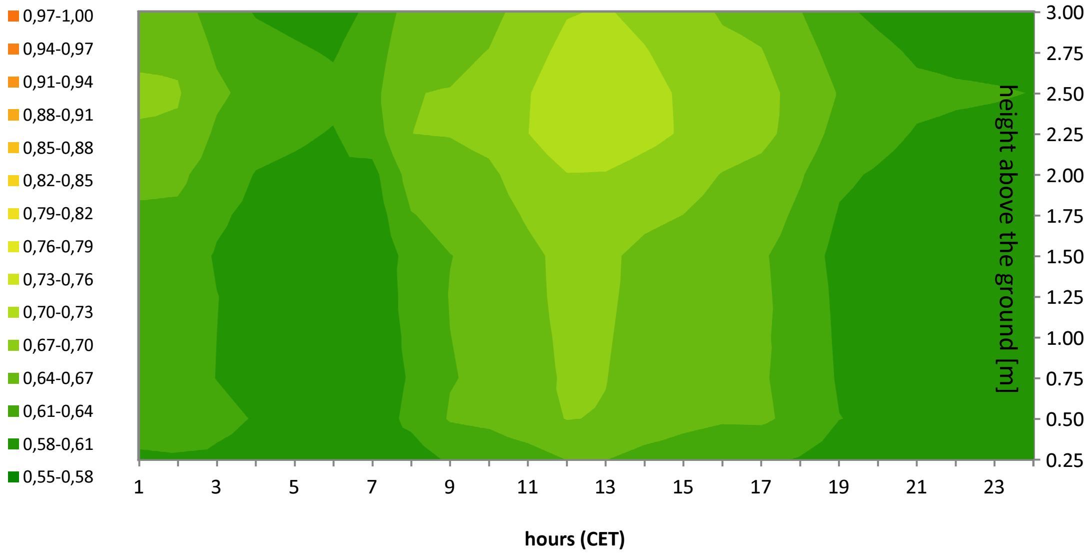


Figure 2. Ratio of the sensible and latent heat (Bowen-ratio) on a low evapotranspiration day (2011.07.29)

It was stated that the maximum of latent heat occurs 1-2 hours earlier in the day than that of the temperature. On days with moderate evapotranspiration (ET_0=2.0-2.4 mm) **(**07.29.2011, **Fig. 2.)**, slight drying process can be recognized as temperature rises only very weakly (proportion of λE falls within the total energy budget). At the time of the maximum drying, it is the strongest above the surface of the maize stand and becomes weaker towards the ground.

For the days of intense evapotranspiration, incoming radiation is high, temperature rises rapidly, and advection effects (wind) are significant. In a mostly advection-free weather pattern on 07.14.2011 (ET_0=4.6-6.8 mm), **(Fig. 3.)** the maximum of latent heat was located apparently on the ground, as a denotation of the intense drying process of the plant stand. Steep gradient of H/λE-ratio also refers to high evapotranspiration rate. In the mid-day hours, H/λE-ratio rose up to near 0.7, reached 0.9 around the boundary layer at the top, and approached 1.0 value above the surface of the maize stand.

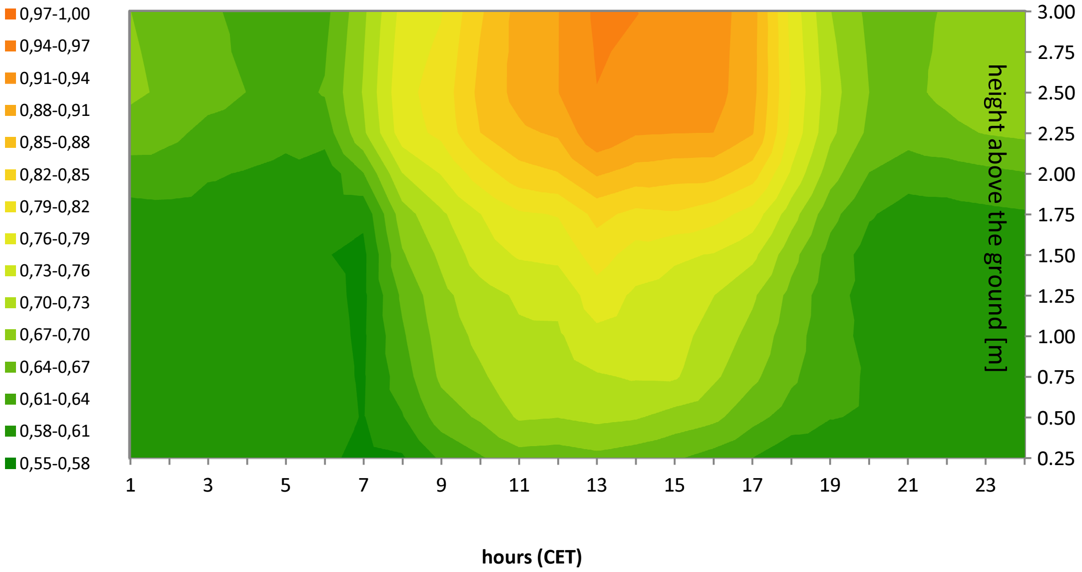


Figure 3. Ratio of the sensible and latent heat (Bowen-ratio) on a high evapotranspiration day (2011.07.14)

The latent heat - that is closely related to the amount of the actual evapotranspiration - is derived from the energy of solar radiation, or more properly, the net radiation (R_n) reduced by soil heat fluxes (G). Relationship between the energy available for evapotranspiration (R_n-G) and the latent heat were evaluated. Results proved that the amount of λE shows close linear relationship with R_n-G. On the basis of the coefficients of determination, dry episodes of the experimental period R_n-G determines the latent heat within maize stands in 98%, while under wet circumstances it is 99%. As a general conclusion, evapotranspiration rate is limited by the radiation budget in 98% of the cases at minimum, and advection effects promote to be the dominant factor only in 2%.

The *actual evapotranspiration of the maize crop* was modelled by the Bowen-ratio method, for the July-September period of 2010 and 2011. In 2010, mean value of β was 0.041, its standard deviation was 0.118, and its coefficient of variation was 288.8%. In 2011, β and its statistical parameters were more balanced; with the mean value of 0.025, standard deviation was 0.041 and the coefficient of variation was 164.0%.

3.3. Statistical and sensitivity analysis and validation of estimation methods for evapotranspiration

Descriptive statistical- and sensitivity analysis of 10 estimation algorithms for potential evapotranspiration were performed on the basis of local climatic data series. In accordance to the results, and using them as sub-models of an IDSS, methods were subjected to a selection procedure.

Based on monthly and yearly amounts of estimated ET_0, it was concluded that evaluation on the basis of seasonal sums is very sensitive to systematic differences between daily model results. Differences of the order of even several hundred millimetres can evolve during a growing season. **(Fig. 4)**.

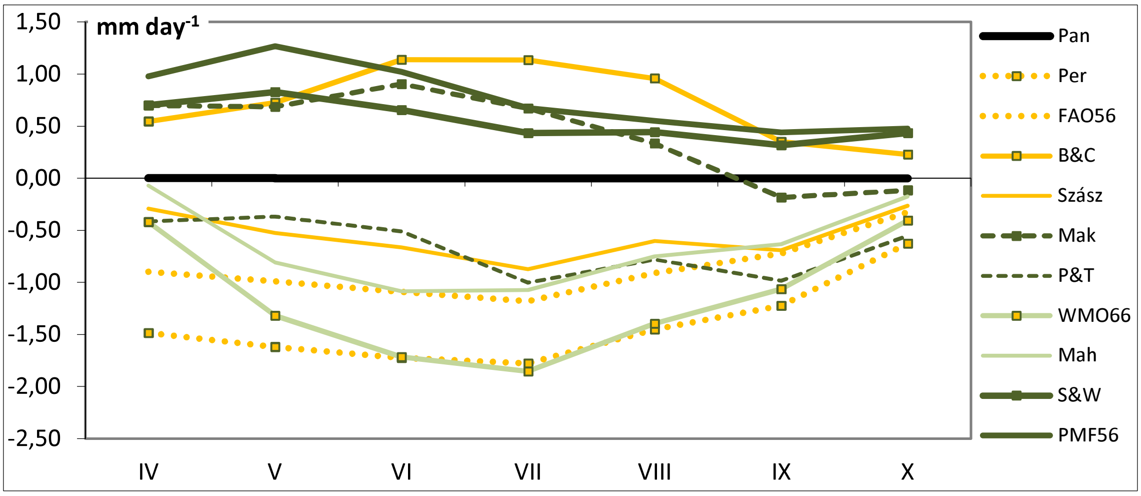


Figure 4. Deviation of model outputs from the A-pan measurements during the vegetation period (2005-2010, April-October)

It was proved that mostly steady but not necessarily constant differences can be found between model outputs, with a non-linear relationship between them. The course of the deviation from the reference during the vegetation period shows close correlation to the precipitation sum. The majority of the models deviate more from the reference pan evaporation during late-spring and summer. For the autumn, the differences reduced due to the lower seasonal values of the evapotranspiration.

On the whole, Blaney-Criddle, Penman-Monteith-FAO-56, Shuttleworth-Wallace and Makkink method resulted in the highest, Pereira, FAO-56, WMO-1966 and Mahringer model in the lowest evapotranspiration sums. On the basis of the seasonal dynamics of the model outputs, mass-transfer based methods (WMO-1966, Mahringer) were generally sensitive, additionally, Pereira, FAO-56, Szász, Makkink and Priestley-Taylor model showed considerable sensitivity for precipitation. Large fluctuation models with high R and St.D. values (Pan, B&C, mass-transfer based and combination-type methods) and 'steady' ones (pan coefficient-based, Szász and P&T methods) with less variability of outputs were specified. Furthermore, mass-transfer-based methods showed wide standard deviation and total range of the output data even in the case of relatively low ET_0 levels. Based on the correlations between the model results, Pereira and FAO-56 models agreed the most to the pan evaporation measurements, while Shuttleworth-Wallace model showed the most similarity to the Penman-Monteith-FAO-56 method. As regards the systematic error, Makkink and Shuttleworth-Wallace model were the closest to pan evaporation, while Shuttleworth-Wallace, Blaney&Criddle and Makkink models were the closest to the Penman-Monteith method.

During the sensitivity analyses, two main groups were defined: the Szász, Makkink, Priestley-Taylor and Penman-Monteith-FAO-56 models can be considered steady, i.e. these methods responded lower fluctuations to the changes of atmospheric variables. At the same time, WMO-1966, Mahringer, Shuttleworth-Wallace methods, the pan evaporation measurements and Pereira model are rather sensitive. These showed large magnitude and high range of changes in ET_0 as a response to the increase or decrease of the four main atmospheric inputs (temperature, air humidity, global radiation and wind). In the light of these conclusions, Priestley-Taylor, Penman-Monteith-FAO-56, and Szász methods were found to be the best performing models for ET calculation.

Taking the data series from *Debrecen-Kismacs* as inputs, the combined type Penman-Monteith-FAO-56 can be characterized with higher, while Priestley-Taylor and Szász- considerably lower (20 and 30 % on average) output results. Model outputs were assessed on the basis of descriptive statistics. It was stated that the total range of the outputs and the standard deviation was the highest for PMF56 model. These parameters are the lowest for Szász method. In this comparison, this model is considered the most robust one. Notwithstanding, Szász model resulted in the highest coefficient of variation (CV), and P&T in the lowest **(Table 1)**.

Table 1. Descriptive statistics for the models assessed (2008-2011, May-Oct.)

mm day^{-1}	**PMF56**	**P&T**	**Szász**
Max.	10.72	7.89	6.74
Min.	0.20	0.29	0.07
Avg.	4.50	3.54	3.19
R.	10.52	7.61	6.67
St.D.	2.10	1.63	1.50
CV	46.7	46.0	47.1
Var.	4.40	2.65	2.25

Max.: absolute maximum, **Min.**: absolute minimum, **Avg**: mean value, **R.**: total range of the data, **St.D.**: standard deviance, **CV(%)**: coefficient of variation, **Var.**: variance, **n** (number of cases)=704

As for their sensitivity, all models gave similar response based on the Debrecen-Kismacs data series. Temperature, air humidity and global radiation had the strongest effect on the outputs, while ET_0 models showed sensitivity to wind the least.

3.4. Utilisation of evapotranspiration data in IDSS – determination of the actual evapotranspiration, system diagnostics

The actual evapotranspiration of maize crop calculated by the FAO IDSS on the basis of reference evapotranspiration was verified by actual evapotranspiration data derived by other methods, in several variants. In the study – concerning practical aspects – the actual evapotranspiration calculated by the model ($ET_{c,FAO}$) was assessed primarily.

Considering the actual evapotranspiration data, it was stated that in comparison with the reference evapotranspiration, it was 90.3%, 92.7% and 98% lower in 2010 and 58.2%, 68.4% and 67.7% lower in 2011, for PMF56, P&T and Szász model, respectively. According to the temporal changes of *mean values of the 3* ET_0 *and* $ET_{c,\ FAO}$ *variation* it was concluded that actual evapotranspiration exceeded the reference ET (for grass) several times, especially in 2011. Coefficients of determination show the closest relationship mostly between the IDSS variant parameterized by ET_0 values of the P&T and Szász sub-model.

For the practical use of the IDSS it has a great importance to know the amount of irrigation water needs indicated by a given magnitude of evapotranspiration, as input. By the FAO IDSS, irrigation water needs of the Kismacs maize stands were estimated, calculating with 8-20 mm daily doses of irrigation water **(Fig. 5.)**. In the growing season of 2010, irrigation needs varied between 0-40 mm amounts of water for 0-2 irrigation events in the middle stage of vegetation period (MID-stage). In 2011 it was 60-160 mm, and all variants signalled the necessity of irrigation. Differences proved to be substantial; P&T and Szász variant calculated less than 40% of the amount simulated by PMF56. All variants signalled irrigation needs for only the initial (INI) and development (DEV) stages, and not for the mid-stage due to the abundant precipitation in July.

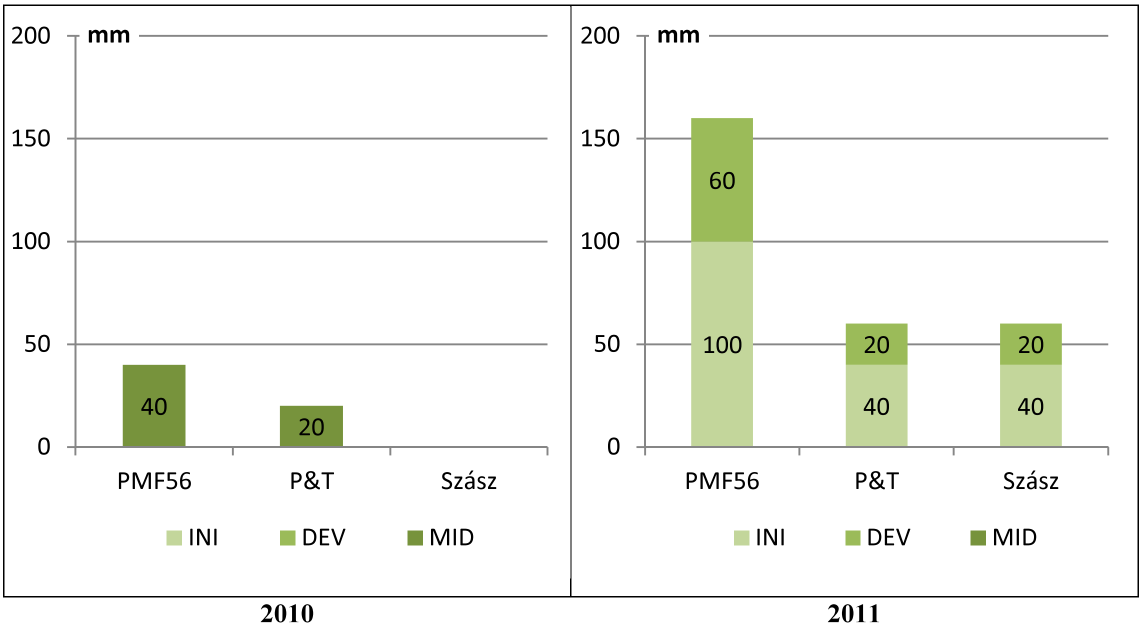


Figure 5. Simulated irrigation water needs by stages of the growing season of maize

Model verification by measured soil water content data series:

Verification of the data series of actual evapotranspiration and the signalled irrigation needs was performed on the basis of gravimetric soil water content data. In the first phase, the 8 days resolution data series were interpolated to daily time step. For the interpolation, variations of the FAO IDSS were applied with different evapotranspiration sub-models. During the test, the accumulated surplus or deficit in the modelled soil water supply was evaluated by the end of every 8 days period.

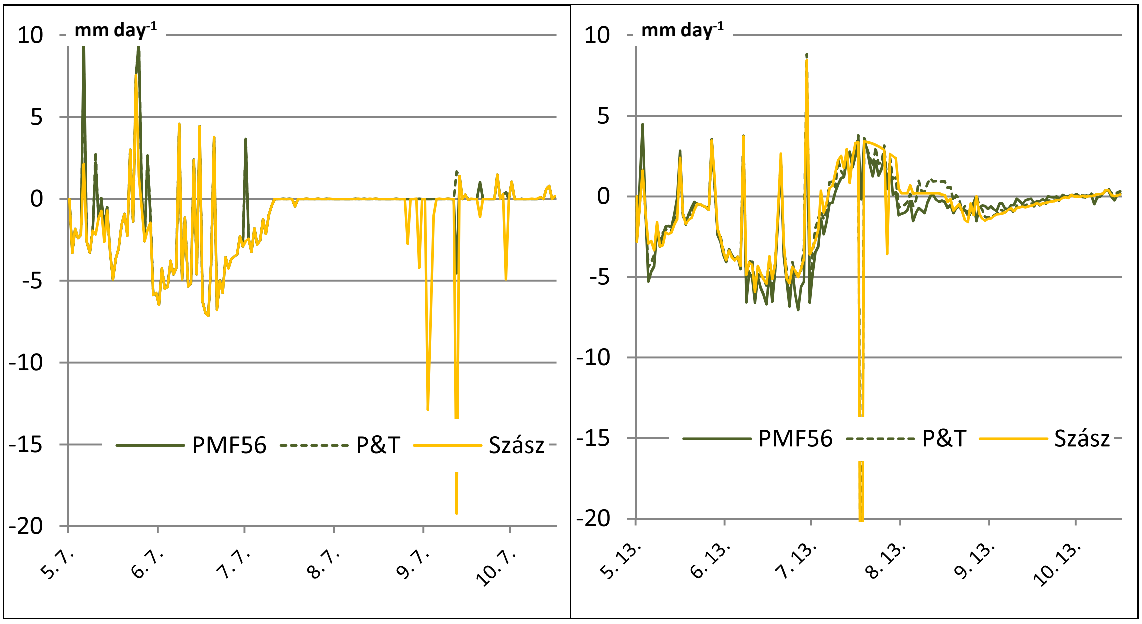
In 2010, PMF56, while in 2011, the estimation of the Szász model variation was the closest to the measured data series at most of the 8 days check-points. The magnitude of the error could not be considered as high as not to allow further use of the results, with the number of 20 (in *2010*) and 13 (in *2011*) cases. In accordance to the results, *for 2010 the PMF56 and for 2011 the Szász*-interpolated variation were accepted as measured data series.

Items of incomes and losses in the water budget generated by the FAO IDSS were calculated, regardless to their correct or false characteristics. Model errors related to deep percolation (DP) and capillary rise (CR) were also determined.

It was concluded, that when the available water (DV) equals to zero in the shallow root zone, the model covers the daily evapotranspiration with *"virtual" capillary rise*. The phenomenon occurs due to the zero value of CR, and although its presence is false in the simulation, it represents a natural process in the actual water cycle. Its amount is minimal however, only 2.7-3.3 mm for a vegetation period, due to the limited magnitude of evapotranspiration. In case of excessive precipitation the model defines the total or a certain part of the precipitation as DP when the shallow root zone became saturated. As *"virtual" capillary rise*, examples can be pointed out from only 2011, when between May 26th and June 6th the model estimated the available water amount zero in the root zone for 6-8 days.

By the daily changes of the available water supplies calculated by the model variants, the sum of the deep percolation losses (DP) and non-ground-water driven (by soil potential gradient) capillary rise (CR) can be determined (–DP+CR). Losses and incomes derived from the evaporation and the effective precipitation (ΔDV) were compared to the daily changes of the measured soil water supply data. In the first third of the 2 growing seasons examined, (INI+DEV stages), water transfer from the deep soil layers proved to be considerable, until the root zone was relatively shallow. The sum of it was 170 *(2011)*-185 *(2010)* mm per vegetation period, decreasing simultaneously with the deepening of the root zone. Daily values reached 5-7 mm, it equals to the 75-95 of the evapotranspiration of the same days on average.

For the water supply estimated by each FAO model variants, sum of all the incomes and losses (–DP+CR) was also calculated, and compared to that of calculated by the measured, reference soil water content. Differences of the values *(ΔDPCR)* are shown in **Fig. 6**.



2010 **2011**

Figure 6. Differences between modelled and measured ΔDPCR values

Modelled values showed considerable differences in comparison with the measured data primarily in the INI and DEV stages, in accordance with the observations introduced above. It was clearly demonstrated on the basis of the actual water supply data that model variations calculated only with *"virtual" CR*, which was originated from the zero value of CR.

Model verification by Bowen-ratio-evapotranspiration data:

Values of the IDSS-modelled actual evapotranspiration ($ET_{c,FAO}$) were compared to the Bowen-ratio method estimation ($ET_{c,BR}$) for the July-August period of both experimental years. In 2010, $ET_{c,FAO}$ variations were estimated lower than the reference $ET_{c,BR}$, particularly for the late July-early August period. Szász method had higher error values, while the other two variant met the reference values more closely. In 2011, similarly high systematic error could not be recognized; modelled actual evapotranspiration was close to the reference, mostly within a ±1 mm interval. Notwithstanding, PMF56 variant estimated high above the other variants and the reference, in several cases (mostly on days of intense evapotranspiration). Due to its lower standard deviation, sum of the absolute error of the P&T variant was the lowest for the total period, while the total value of the error – taking the sign of the values into consideration, too – was the lowest for the Szász variant. It was stated that during a 62 days long period the Szász variant deviated only 2 mm from the reference, while the deviance of the lowest standard deviation variant, P&T was higher.

Summarizing the observations of this part of the study, in 2010 the P&T and PMF56 variants showed the closer agreement with the reference Bowen-ratio ET_c. Standard deviation of the P&T were similar to that of the reference data series, and it was in close correlation to the reference in both experimental years. In 2011, the Szász variant showed the lowest error, despite of its higher standard deviation. PMF56 variant resulted in the highest, while Szász the lowest ET_c values, while P&T estimated medium high values with moderate fluctuations. Taking the results of the 2011 period in consideration, P&T and Szász-variants can be highlighted. Additionally, in spite of the higher standard deviation of its output, the low error level of the Szász method was confirmed by the reference data.

For the purpose of validation, crop coefficient (K_c) was calculated. It can be defined as the ratio of the *reference- and the actual evapotranspiration*. Higher values were observed typically in 2011 when K_c was 0.1 higher on average, while in 2010 K_c values were set around 1.0. The same analysis was performed for the transpiration (K_{cb}) and the evaporation

(K_e) terms, too. Comparing the calculated values on the basis of $ET_{c,BR}$ to the modelled data, fluctuation of the calculated ones was found significantly higher due to the changeable evapotranspiration rate in the growing season of 2011, particularly.

4. NEW SCIENTIFIC RESULTS OF THE THESIS

1. A mobile measurement system has been developed for the determination of the distribution and the fluxes of the latent and sensible heat within the plant stand. On the basis of the gathered database, the actual evapotranspiration of the maize stand was calculated.

2. By performing statistical- and sensitivity analyses of 10 estimation models for potential evapotranspiration, the most suitable methods were outlined based on their correlation to the pan evaporation data series measured at the Debrecen-Airport station and the sensitivity shown to the wind speed. It was also clarified that air temperature, air humidity and global radiation affected the magnitude of the output values the most.

3. Using the FAO irrigation decision support system, actual evapotranspiration of the maize crop was modelled by 3 model variations, for the growing seasons of 2 years with different precipitation regimes. Accomplishment of the model variations was evaluated on the basis of the calculation of the irrigation water needs of maize stands in Debrecen-Kismacs study site. Results were verified by gravimetric soil water content measurements. For the 2 experimental years (2010 and 2011), different models proved to be best for practical application.

4. The total water budget of maize stands was determined, false income and loss items of the water balance estimated by the FAO IDSS were calculated, and incorrect calculations related to the deep percolation and capillary rise were outlined.

5. Modelled values of the actual evapotranspiration were compared to the estimation by the Bowen-ratio balance method. In 2010, the Priestley-Taylor and Penman-Monteith-FAO-56, in 2011, the Priestley-Taylor and the Szász methods were found more applicable.

6. Crop coefficients, representing the ratio of the potential and actual evapotranspiration of the maize stand were calculated for the estimated data series of the FAO IDSS and the Bowen-ratio method, respectively. The dynamics of the parameters during the vegetation period were characterized and descriptive statistics were performed.

5. USABILITIY OF THE RESULTS IN PRACTICE

- Within plant stands, accurate and detailed measurements can be performed by our specifically developed measuring system. Beyond the pure descriptive characterization of the micro-climate of plant stands, a detailed database is obtainable for the purpose of calculation of the actual evapotranspiration. The calibrated data-loggers are suitable for horizontal measurements, too, for example, in studies related to edge-effect or oasis-effect. The system is suitable for various plant stands and provides a simple and reliable opportunity for automated, high resolution data logging.

- Micro-climatic measurements performed within plant stands were conducted for the purpose of characterization of the latent and sensible heat fluxes. On the basis of the database gathered, another approach was taken into consideration for calculation of actual evapotranspiration. It served as a reference during model validation on one side, and also meant a low-input alternative for the estimation actual evapotranspiration for various purposes.

- By the complex tests of estimation models for evapotranspiration within the agro-ecological conditions of Hajdúság region, rich background information was provided for applications using evapotranspiration as an input. For the estimation of potential and actual evapotranspiration, a great number of methods can be found. It is considered a main principle that considering local experiences, results of scientific studies has a great importance in the selection of the estimation algorithms.

- Out of the several ones, FAO irrigation decision support system was selected for test simulations. During the tests, evaporation sub-models were subjects of further analyses, and on the other hand, functioning of the FAO model-complex was evaluated in terms of diagnostics and error assessment. Our study contributed the improvement of the IDSS, and answered several questions regarding the relationship between the magnitude of evapotranspiration and the irrigation water needs.

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