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ANALYSES OF SPRING BARLEY EVAPOTRANSPIRATION RATES BASED ON GRADIENT MEASUREMENTS AND DUAL CROP COEFFICIENT MODEL

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Abstract

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The yield of agricultural crops depends on water availability to a great extent. According some projections, the likelihood of stress caused by drought is increasing in future climates expected for the Central Europe. Therefore, in order to manage agro-ecosystems properly, it is necessary to know water demand of particular crops as precisely as possible. Evapotranspiration (ET) is the main part of water balance which takes the water from agro-ecosystems away. The ET consists of evaporation from the soil (E) and transpiration (T) through the stomata of plants. In this study, we investigated ET of spring barley 1-ha field (Domanínek, Czech Republic) measured by Bowen ratio/energy balance method during growing period 2013 (May 8 to July 31). Special focus was dedicated to comparison of barley ET with the reference grass ETo calculated according FAO-56 model, i.e. the determination of barley crop coefficient (K_c). This crop coefficient was subsequently separated into soil evaporation (K_e) and transpiration fraction (K_{cb}) by adjusting soil and phenological parameters of dual crop coefficient model to minimize the root mean square error between measured and modelled ET. The resulting K_{cb} of barley was 0.98 during mid-growing period and 0.05 during initial and end periods. According to FAO-56, typical values are 1.10 and 0.15 for $K_{cb\ mid}$ and $K_{cb\ end}$, respectively. Modelled and measured ET show satisfactory agreement with root mean square error equal 0.41 mm. Based on the sums of ET and E for the whole growing season of the spring barley, ET partitioning by FAO-56 dual crop coefficient model resulted in E/ET ratio being 0.24.

Keywords: evapotranspiration, dual crop coefficient model, Bowen ratio/energy balance method, transpiration, soil evaporation, spring barley

INTRODUCTION

Water availability is a limiting factor for plants and thus has a great impact on the yields of agricultural crops. In the changing climate it becomes increasingly important to understand better how particular crops perform in water stress conditions. Moreover, it is of our interest how effectively the crops are able to use the water, since the dry periods become more frequent (Trnka *et al.*, 2011; Hlavinka *et al.*, 2009). The main part of the water balance that transports the water away from the agro-ecosystems is evapotranspiration (ET). Evapotranspiration comprises two parts: evaporation from the soil (E) and transpiration (T) through the stomata of plants (Kool *et al.*, 2014). There is also an interception from the wet vegetation's surface but for the purposes of our study it is considered as part of E. Generally, T is considered as a desirable component of ET as this water loss is compromised by plant productivity. This is because stomata regulate both, water loss and carbon dioxide uptake, and its quantity is often described as the water-use efficiency (Larcher, 2003). In contrast, E is accounted as a source of unnecessary water loss, though some positive impacts on plants like a decrease of the air vapour pressure deficit and air cooling should be considered (Tolk, 1995). Exact knowledge of the crop ET is also fundamental for both sustainable agricultural practices and irrigation scheduling. To improve water management practices and ensure high biomass productivity by avoiding stress conditions, ET partitioning is of particular importance. According to Kool *et al.* (2014) in 32 out of 52 examined studies focusing on ET partitioning, E/ET ratio was found higher than 30%. This confirmed their hypothesis that E often constitutes a large fraction of ET and therefore deserves an independent consideration.

In general, ET can be either measured or modelled. Measurements include methods like eddy covariance, scintillometry, Bowen ratio/energy balance method (BREB), lysimeters, soil water balance measurements, etc. Measurements are necessary however, precise measurements are difficult to be maintained continuously in a wide range of representative conditions. In addition, they are costly, time-consuming and demand experienced persons. On the other hand, models can be used to estimate ET of any place and for any time if the basic input data are available but they need measurements for their calibration and validation. One of the simplest ways to model ET is based on a crop coefficient which is in fact the ratio between an actual and reference ET (Doorenbos and Pruitt, 1975; Allen *et al.*, 1998). Reference evapotranspiration (ETo) is the evapotranspiration rate from a reference surface, i.e. hypothetical grass crop with specific physiological and aerodynamic characteristics, not short of water and nutrients, and with no symptoms of diseases (Allen *et al.*, 1998). The ETo expresses the evaporating power of the atmosphere at a specific location and time and does not consider the crop characteristics and soil factors. The ETo can be computed from weather data because the only factors affecting ETo are climatic parameters (Allen *et al.*, 1998). On the other hand, actual evapotranspiration (ET) is the ET of particular crop at particular place and time which takes into account also the plant characteristics and stress caused by non-standard conditions, i.e. pests and diseases, soil fertility, water shortage or water logging etc. (Allen *et al.*, 1998).

In this study, we used gradient-measurements-based BREB method (Bowen, 1926; Savage, 2010) to measure ET. To separate ET semi-empirical approach called FAO (Food and Agriculture Organization) dual crop coefficient model (Allen *et al.*, 1998) is employed. Finally, our awareness of how the ET is split into soil evaporation and plant transpiration improves our understanding of the plants' water use efficiency.

The goals of our study were:

1. To test the FAO-56 dual crop coefficient model against BREB measurements at 1-ha spring barley field in rain fed area of Bohemian-Moravian Highlands.
2. To use the FAO model to separate ET into transpiration and evaporation components.

MATERIALS AND METHODS

In presented study the data recorded during the season 2013 at an experimental field in Bystřice nad Pernštejnem (Czech Republic, 49° 31´ N, 16° 14´ E and altitude 530 m a.s.l.) were used. Experimental field was sown by spring barley (*Hordeum vulgare*) variety Bojos on 18th April 2013. It was fertilized with 60 kg of N ha^{-1} 17th of May 2013. To gain all necessary data, an automatic weather station with BREB system was placed close to the centre of 1-ha barley field in order to maximize the distance from the field edge downwind with respect to prevailing wind direction. Since 7th of May 2013 until 31st of July air temperature and humidity were recorded at two levels above the canopy using the integrated temperature-humidity sensors EMS33R. At the beginning of the growing season they were 0.2 m and 1.2 m high. As the barley was growing the heights of the sensors were increased in order to keep the lower one always 0.1 m above the plant surface and the upper one just 1 meter above the lower sensor. At the end of the growing period of barley the sensors were in 0.9 m and 1.9 m, respectively. The net radiation (W/m^2) and soil heat flux (W/m^2) were recorded by sensors Schenk 8110 and heat flux plate HFP01. Further, precipitation was measured by rain gauge Met One 380 and wind speed and wind direction by anemometer Met One 034B. All sensors were connected to data logger RailBox V32P6 scanning at 30-s intervals and storing 10 min averages. The data were used to calculate actual evapotranspiration (ET) of the spring barley based on BREB method. Another automatic weather station using compatible sensors was placed on nearby turf grass and used for ETo calculation. Turf grass around the station is cut periodically to maintain the reference grass cover 0.05 m high. The air temperature, air humidity, and wind speed were measured in standard 2 m height. The net radiation and soil heat flux were also recorded.

The BREB method uses the measurements of the air temperature and air humidity gradients, radiation balance and the soil heat flux (Savage *et al.*, 2009). In particular, the BREB method is based on the energy balance equation and the theory of turbulent diffusion (K-theory) (Savage, 2010). The simplified energy balance equation neglecting the energy used in photosynthesis and energy stored in canopy can be written as follows:

$$R_n = \lambda ET + H + G, \tag{1}$$

where R_n is the net radiation flux, H and λET are sensible heat and latent heat fluxes respectively, G is soil heat flux (all in Wm^{-2}) (Perez *et al.*, 1999).

The Bowen ratio (β) is defined as the ratio of the sensible heat flux to the latent heat flux and can be described as:

$$\beta = \frac{H}{\lambda ET} = \frac{\lambda \Delta T}{\Delta e}, \tag{2}$$

where γ is the psychrometric constant (~ 0.066 kPa K^{-1} at the sea level) and ΔT and Δe are the temperature and vapour pressure differences between the two levels above surface (Bowen, 1926). This equation results from application of the theory of turbulent diffusion where the exchange coefficients of heat and vapour are assumed to be equal, known as the Bowen ratio similarity principle (Bowen, 1926), where the scalars are assumed to be carried by the same eddies if they have identical or very similar source and sink distributions.

Thus, it is possible to calculate the Bowen ratio by measuring air temperature (T in K) and water vapor pressure (e in kPa) at two different levels in the atmosphere. Further it allows us to calculate λET by combining Eqs. 1 and 2 (the radiation balance and the Bowen ratio) which results in an equation (Guo *et al.*, 2007):

$$\lambda ET = \frac{(R_n - G)}{(1+\beta)}. \tag{3}$$

To calculate reference evapotranspiration (ETo) in this study FAO Irrigation and Drainage Paper No. 56 was followed (Allen *et al.*, 1998). As the reference, hypothetical surface of grassland has been adopted with standard characteristic for reference crop of 0.12 m high, albedo of 0.23 and not limited by water or nutrient and thus with a fixed surface resistance (r_c) of 50 and 200 s m^{-1} for diurnal and nocturnal periods, respectively (Allen 2003). Using these parameters, ETo was then calculated using the Penman-Monteith combination equation which can be written in the final form (Monteith, 1965):

$$\lambda ET = \frac{\Delta(R_n - G) + c_p \rho_a \frac{e_{sat} - e}{r_a}}{\Delta + \gamma\left(1 + \frac{r_c}{r_a}\right)}, \tag{4}$$

where (kPaK^{-1}) is the first derivation of the function e_{sat} versus T known as the saturation vapour pressure curve where e_{sat} is saturation vapour pressure (kPa) at the evaporating water surface and r_a is aerodynamic resistance of reference grass cover with constant height 0.12 m (Allen *et al.,* 1998). Vapour pressure (e), air temperature (T) and wind speed were measured in standard 2 m height above reference grass cover. The 30 min measured mean values were used to determine ETo half hourly and subsequently the daily sums of ET_0 were calculated. Subsequently, barley crop coefficient (K_c) was calculated as a ratio between actual evapotranspiration (ET) of barley and reference evapotranspiration (ET_0). It can be expressed as follows:

$$K_c = \frac{ET}{ET_0}. \tag{5}$$

Crop coefficient can be either single or dual. The single crop coefficient integrates the effect of both crop transpiration and soil evaporation (Allen *et al.*, 1998). On the contrary, dual crop coefficient separates them into two coefficients: a basal crop coefficient (K_{cb}) to describe plant transpiration, and a soil water evaporation coefficient (K_e). Single crop coefficient K_c is replaced by:

$$K_c = K_{cb} + K_e. \tag{6}$$

The purpose of the calculation should be considered when choosing the appropriate approach. The dual K_c is more complicated and more computationally intensive. It suits better research purposes, real time irrigation scheduling or detailed soil and hydrologic water balance studies while single K_c approach is easier and can be applied for basic irrigation schedules (Allen *et al.*, 1998).

In this study we are using dual K_c. The actual crop ET is then calculated as:

$$ET = (K_{cb} + K_e)ET_0 = K_c ET_0. \tag{7}$$

In present study, a dual crop coefficient model FAO-56 was used according to Allen *et al.* (1998). The crop coefficients ($K_{cb\ ini,\ mid\ and\ end}$), phenological (length of the initial, development, mid and late season stages), and soil water balance parameters were determined specifically for our site. In particular, soil water balance parameters consisted of information on the field capacity (Fc), wilting point (Wp), maximum root depth (Root max), readily evaporable water from the superficial soil layer (REW), and average fraction of total available soil water (TAW) that can be depleted from the root zone before onset of reduction in ET (p). The above-mentioned parameters can be seen in Tab. I and were constrained within physical ranges reported in literature or within ±10% to our own observations and solved iteratively to get the smallest root mean square error (RMSE) between ET measured by BREB and ET estimated by the dual crop coefficient model FAO-56.

During the growing season plant area index (PAI) of spring barley was measured periodically using ceptometer based system SunScan (Delta-T Devices ltd., UK). The PAI is the area of all plant tissue, including stems that intercept light and contribute to the measured value. Leaf Area Index (LAI), on the other hand, is one-sided green leaf area per unit ground surface area (LAI = leaf area/ground area, m^2/m^2) (Watson, 1947). The PAI is preferred to LAI in this study because not only leaves but total above ground biomass was measured. The PAI data were used to determine the fraction of soil exposed to sunlight using Beer-Lambert law (Larcher, 2003). The field campaign finished before barley was harvested and so our dataset finishes 31st July 2013.

RESULTS AND DISCUSSION

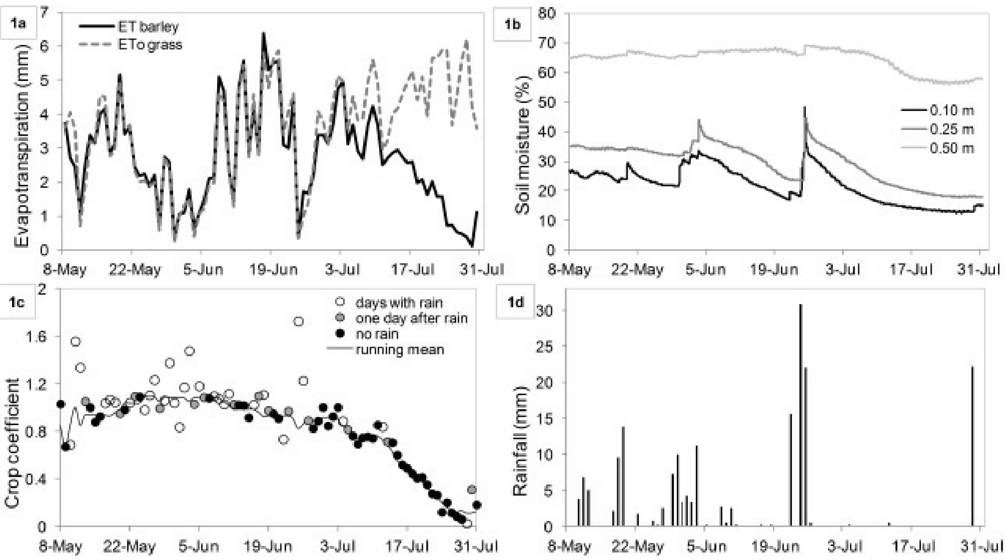
The actual evapotranspiration of spring barley (ET) and reference evapotranspiration (ETo) for period between 8th of May 2013 and 31st July 2013 are shown in Fig. 1a. During the whole period ET total was 229.4 mm and ETo 300.7 mm. The mean daily ET and ETo were 2.7 mm and 3.5 mm, respectively. Fig. 1b shows the course of soil moisture in three depths as a consequence of precipitation during the growing season presented in Fig. 1d. During the 85 days of measurement, rain fell on 30 days which is 35% of time. The ET that occurred on these days formed 30% of ET of the growing season. In total 184.8 mm rain fell during the growing season, 36% of which fell in May (67.2 mm), 51% in June (94.6 mm) and only 23 mm in July (12% of total precipitation).

It is obvious from the Fig. 1a that towards the end of the growing period ET of barley is declining. The values of ETo were notably higher than ET. The reason might be that the spring barley plants were experiencing some shortage of water especially in the top soil horizons. The lack of rainfall events in July shown in Fig. 1d supports this assumption. However, there is no evidence on decline of water accessibility shown by K_{cb} in Fig. 3. More likely, the diminishing ET at the end of the growing period was caused by natural decrease of ET as the transpiration lessens toward yellow ripeness stage.

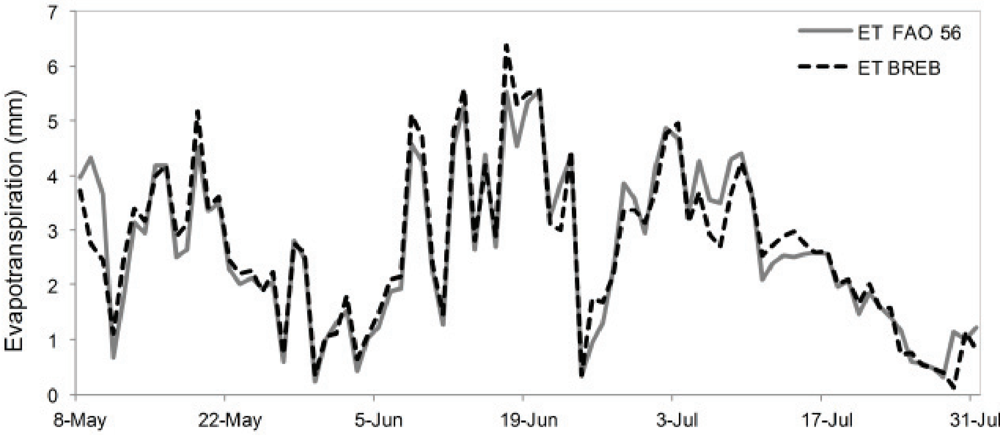
Fig. 1b displays daily values of single crop coefficient (K_c) divided to three groups according to rainfall. There are different points distinguishing days with rain, days after rain and two or more days after rain. The K_c was calculated as a rate between actual evapotranspiration calculated using BREB approach and reference ETo (Fig. 1a). Single crop coefficient integrates crop characteristics and averaged effects of evaporation from the soil (Allen *et al.,* 1998). More complicated, dual K_c approach, is needed when we need daily values of K_c for specific fields of crops and for specific years. Then transpiration and evaporation coefficient ($K_{cb} + K_e$) must be separate.

Our results show more scatters from running mean for rainy days. Higher divergence is a consequence of higher actual ET of barley after rain when intercepted water with almost zero surface resistance is evaporating intensively. From the shape of the curve of running mean it is obvious that, at the end of the period, ET of spring barley was much lower than ETo as a consequence of reduced transpiration of barley and dry weather at the end of the season.

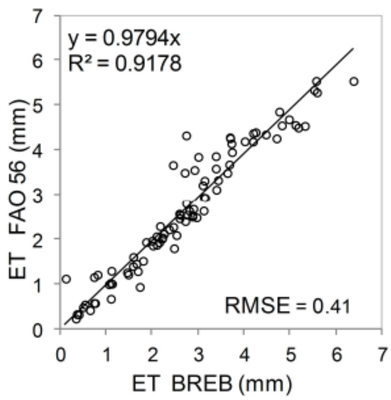
For the purposes of this study ET was not only measured but also modelled using FAO-56 dual crop coefficient model. The seasonal course of modelled and measured ET can be seen in Fig. 2 indicating very high agreement. The total ET by model equals 226.2 mm which is underestimated only by 3.2 mm compared to BREB method. Fig. 3 shows



1: *1a: Daily totals of spring barley actual ET measured by BREB and reference ETo in mm in Domanínek during growing period 2013; 1b: Soil moisture in Domanínek during growing period of barley in 2013 in three depths; 1c: Single crop coefficient (Kc) of barley in growing period 2013 in Domanínek divided according to precipitation to 3 groups and its running mean over 7 days; 1d: Precipitation totals during growing period of barley in 2013 in Domanínek*



2: *Seasonal course of daily evapotranspiration totals of barley measured by BREB and estimated using the FAO 56 dual crop coefficient model for growing period 2013 in Domanínek*



3: *Scatter-plot view describing the relation between actual barley ET measured by BREB and ET modelled using FAO-56 for growing period 2013 in Domanínek with basic descriptive statistics*

I: *Basal K_c and its parameters resulting from the root mean square error minimizing procedure*

Basal K_c		Crop Development Stages (days):		Computed Dates for Stages:		Evaporation parameters	
$K_{cb\ ini}$	0.05	L_{ini}	30.00	J_{Plant}	1	REW	12.81 mm
$K_{cb\ mid}$	0.98	L_{dev}	14.00	J_{Dev}	130	Root max	0.65 m
$K_{cb\ end}$	0.05	L_{mid}	42.66	J_{Mid}	144	Fc	0.36%
		L_{late}	22.62	J_{Late}	187	Wp	0.16%
				J_{Harv}	209	p	0.60

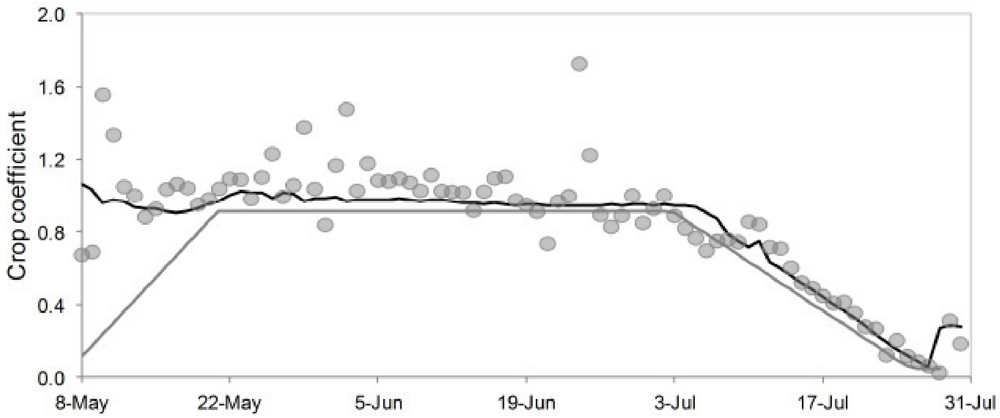
*REW – readily evaporable water, Fc – field capacity, Wp – wilting point, p – evapotranspiration depletion factor, Root max – maximum root depth

the statistics of the modelled and measured ET as a result of iterative parameterization. The coefficient of determination and the slope of the regression line indicate very good fit between ET modelled by FAO-56 and ET measured using BREB method with RMSE 0.41 mm. The variability in a data set is described by the coefficient of determination R^2 equal 0.92. The parameters and crop coefficient resulting from this RMSE minimizing procedure can be seen in Tab. I.

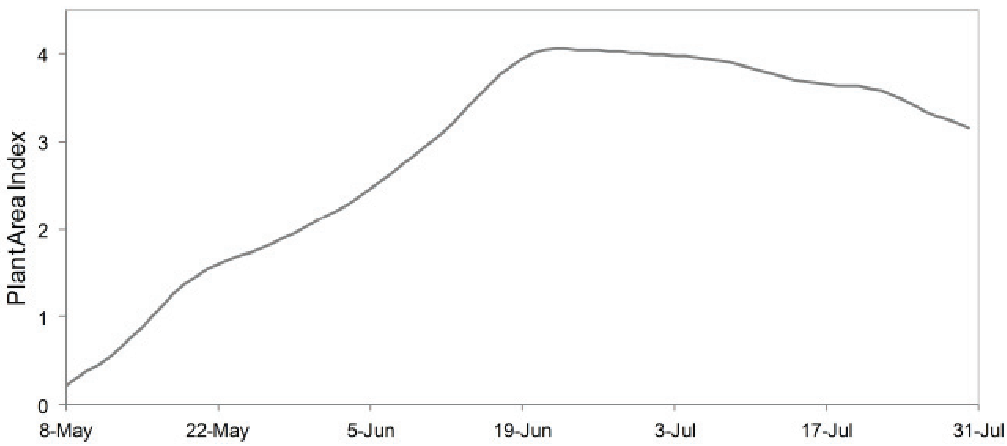
The dual crop coefficient can be seen in Fig. 4. The basal crop coefficient describes plant transpiration and is associated with conditions of minimum soil evaporation but not water limitation for plants (Allen *et al.*, 1998; Paco *et al.*, 2012). The soil water evaporation coefficient describes evaporation from the soil surface. It is necessary to mention that in FAO-56, values listed for K_c represent ET under growing conditions with a high level of management and with little or no water or other ET reducing stresses and thus represent what is referred to as potential levels for crop ET (Allen *et al.*, 2005). Fig. 4 shows both basal crop coefficient (K_{cb}) and soil evaporation coefficient (K_e). The Ke is the difference between the two K_c lines in the picture. Fig. 5 shows PAI of spring barley recorded during the growing period. It can be seen that mid period starts when plant area index is 1.64

and it finishes when PAI is equal 3.97. K_{cb} for initial period is 0.05, K_{cb} mid is 0.98 and K_{cb} end is equal also 0.05. According to FAO-56 (Allen *et al.*, 1998), the typical values for spring barley are 1.1 for $K_{cb\ mid}$ and 0.15 for $K_{cb\ ini}$ and $K_{cb\ end}$.

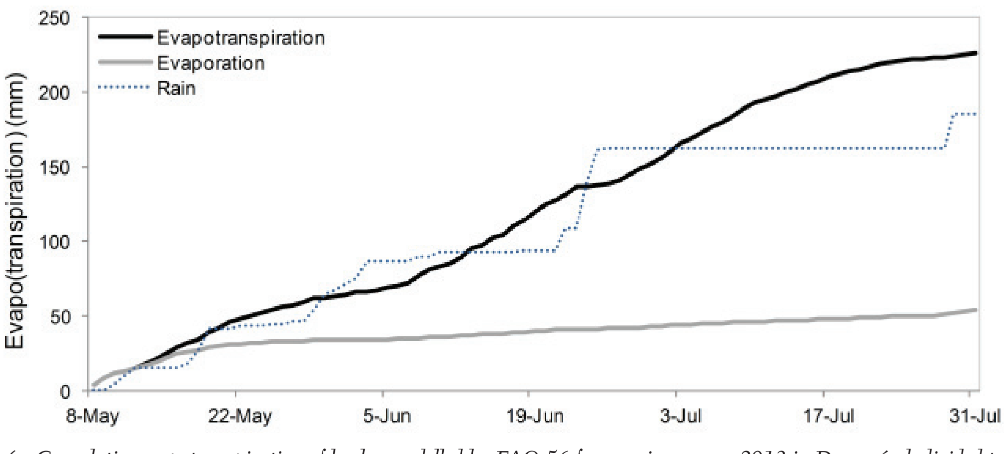
As a secondary product of FAO-56 dual crop coefficient model ET was split into evaporation and transpiration. Fig. 6 demonstrates how evapotranspiration is divided between evaporation and transpiration by the FAO-56 model. This fulfils the second objective of presented study.



4: *Basal crop coefficient (Kcb) (grey line) and soil evaporation coefficient (Ke) (difference between grey and black lines) compared to the actual crop coefficient (grey closed circles) as the ratio between actual ET of barley measured by BREB and reference ETo*



5: *Plant Area Index of spring barley during growing period 2013 in Domanínek*



6: *Cumulative evapotranspiration of barley modelled by FAO-56 for growing season 2013 in Domanínek divided to evaporation form soil (gray line) and transpiration (difference between black and gray line), and cumulative precipitation*

At the beginning of the growth of barley evaporation from the soil in principal equals to ET while toward the end of the growing season evaporation represents about one quarter (24%) of cumulative ET. The total ET for the whole growing period is 226.2 mm and total E is 53.8 mm. The E/ET ratio for spring barley based on these sums is then 0.24. Compared to literature we can only use one known example of ET partitioning for the same crop. Allen (1990) used different methodology in his study. For estimating E, he used micro-lysimeters and ET was determined by soil water balance measurements using neutron probe. The result E/ET accounted for 0.67–0.77 depending on different fertiliser treatment. Difference in our findings could be explained by the different plant density. In our study spring barley sowing density was 400 seeds per square meter. As a result we can have more than 900 tillers per square meter. In contrary, in Allen's (1990) experiment their average final density was 200 tillers per square meter. This means that in our case more soil was covered by plants in higher rate which increased relative role of transpiration. In Allen's experiment, more soil was uncovered and exposed to radiation, wind and vapour pressure deficit increasing soil evaporation. At the same time, fewer plants present on the site transpired less than in our experiment. Finally, we must take the climatic difference into account. Another study dealing with ET partitioning was conducted on irrigated wheat field in India (Balwinder-Singh *et al.*, 2011). Depending on a treatment with or without mulch their E/ET ratio reached values between 0.29 and 0.40. In their experiment daily E was measured using mini-lysimeters, and total seasonal ET was estimated as the missing term in the water balance equation (Balwinder-Singh *et al.*, 2011). Two more experiments conducted in China are closer to our results. In particular, Fan *et al.* (2013) came to result of E/ET ratio between 0.30–0.45 for their wheat experiment depending on tillage system and irrigation treatment. Similarly, Liu *et al.* (2002) found the E/ET ratio to be 0.30 for winter wheat and maize.

CONCLUSIONS

In agriculture water is a limiting factor of the yields and in the present changing climate it is important to understand how crops deal with water shortage. Precise information about evapotranspiration is a key as it is the main losing part of the water balance. Measurement of ET on site is not feasible everywhere and that is why modelling plays its significant role. The main aim of this study was to test the FAO-56 dual crop coefficient model against BREB measurements on spring barley field in Bohemian-Moravian Highlands in 2013. Our results show robustness and reliability of the FAO-56 dual K_c model in reproducing daily dynamic of barley ET measured by BREB. Therefore, we used the model to separate ET into transpiration and evaporation components and fulfil the second goal of the study. This attitude narrows down real plant activity and separates it from soil evaporation which is considered to be a non-productive component of evapotranspiration. Our study represents the first application of FAO-56 dual crop coefficient in the Czech Republic. More investigation is needed to find robust and reliable parameters necessary to feed FAO-56 dual K_c model which may potentially provide better ET estimates compared to widely used single crop coefficient models.

SUMMARY

In the present changing climate it is important to understand how agricultural crops deal with water. Main focus in agro ecosystems is on evapotranspiration as it is the loosing part of water balance. In this study, measured and modelled ET of spring barley was used. Measurement took place in experimental field in Domanínek, Czech Republic in 2013. For modelling ET model FAO-56 dual crop coefficient was applied. The results show very good agreement. Moreover, FAO-56 dual K_c model was used to separate soil evaporation from the evapotranspiration. This is particularly important for deeper understanding of water use efficiency of crops. Only transpiration is considered as a wanted component of ET (it is related to plant productivity) whereas evaporation form the soil is considered as undesired water loss. Our estimation of E/ET ratio was satisfactory. However, for more robust and reliable parameters further investigation is needed.

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REFERENCES

ALLEN, S. J. 1990. Measurement and estimation of evaporation from soil under sparse barley crops in Northern Syria. *Agric. For. Meteorol.*, 49: 291–309.

ALLEN, R. G. 2003. *Crop coefficients. Encyclopaedia of Water Science*. DOI: 10.1081/E-EWS 120010037.

ALLEN, R. G., PEREIRA, L. S., RAES, D., SMITH, M. 1998. Crop evapotranspiration. In: *Guidelines for Computing Crop Water Requirements.* FAO Irrigation and Drainage Paper No. 56, pp. 290.

ALLEN, R. G., PEREIRA, L. S., SMITH, M., RAES, D., WRIGHT, J. L. 2005. FAO-56 dual crop coefficient method for estimating evaporation from soil and application extensions. *J. Irrig. Drain. Eng.*, 13: 2–13.

ALLEN, R. G., PRUITT, W. O., WRIGHT, J. L., HOWELL, T. A., VENTURA, F., SNYDER, R., ITENFISU, D., STEDUTOH, P., BERENGENA, J., YRISARRY, J. B., SMITH, M., PEREIRA, L. S., RAES, D., PERRIER, A., ALVES, I., WALTER, I., ELLIOTT, R. 2006. *A* recommendation on standardized surface resistance for hourly calculation of reference ETo by the FAO56 Penman-Monteith method. *Agric. Water Manage.*, 81: 1–22.

BALWINDER-SINGH, EBERBACH, P. L., HUMPHREYS, E., KUKAL, S. S. 2011. The effect of rice straw mulch on evapotranspiration, transpiration and soil evaporation of irrigated wheat in Punjab, India. *Agric. Water Manage.,* 98: 1847–1855.

BOWEN, I. S. 1926. The ratio of heat losses by conduction and evaporation from any water surface. *Phys. Rev.*, 27: 779–787.

DOORENBOS, J. and PRUITT, W. O. 1975. *Guidelines for predicting crop water requirements, Irrigation and Drainage Paper No. 24.* FAO-ONU, Rome, Italy. 168 pp.

FAN, Z., CHAI, Q., HUANG, G., YU, A., HUANG, P., YANG, C., TAO, Z., LIU, H. 2013. Yield and water consumption characteristics of wheat/maize intercropping with reduced tillage in an Oasis region. *Eur. J. Agron.*, 45: 52–58.

FISCHER, M. 2012. *Water balance of short rotation coppice*, Brno: Mendel University in Brno, Faculty of Agronomy, Department of Agrosystems and Bioclimatology. Ph.D. thesis, 261 pp.

GUO, X., ZHANG, H., KANG, L., DU, J., LI, W., ZHU, Y. 2007. Quality control and flux gap filling strategy for Bowen ratio method: revisiting the Priestley–Taylor evaporation model. *Environ. Fluid. Mech.*, 7: 421–437.

HLAVINKA, P., TRNKA, M., SEMERÁDOVÁ, D., DUBROVSKÝ, M., ŽALUD, Z., MOŽNÝ, M. 2009. Effect of drought on yield variability of key crops in Czech Republic. *Agric. For. Meteorol.*, 149: 431–442.

KOOL, D., AGAM, N., LAZAROVITCH, N., HEITMAN, J. L., SAUER, T. J., BEN-GAL, A. 2014. A review of approaches for evapotranspiration partioning. *Agric. For. Meteorol.*, 184: 56–70.

LARCHER, W. 2003. *Physiological Plant Ecology*. 4th edition. Berlin: Springer.

LIU, CH., ZHANG, X., ZHANG, Y. 2002. Determination of daily evaporation and evapotranspiration of winter wheat and maize by large-scale weighing lysimeter and micro-lysimeter. *Agric. For. Meteorol.,* 111: 109–120.

MONTEITH, J., 1965: Evaporation and environment. In: *19th Symposia of the Society for Experimental Biology*. Cambridge: University Press, 205–234.

PACO, T. A., FERREIRA, M. I., ROSA, R. D., PAREDES, P., RODRIGUES, G. C., CONCEIC, N. 2012. The dual crop coefficient approach using a density factor to simulate the evapotranspiration of a peach orchard: SIMDualKc model versus eddy covariance measurements. *Irrig. Sci.*, 30: 115–126.

SAVAGE, M. J., EVERSON, C. S., METELERKAMP, B. R. 2009. Bowen ratio evaporation measurement in a remote montane grassland: Data integrity and fluxes. *J. Hydrol.*, 376: 249–260.

SAVAGE, M. J., 2010: Field evaluation of polymer capacitive humidity sensors for Bowen ratio energy balance flux measurements. *Sensor,* 10: 7748–7771.

TOLK, J. A., HOWELL, T. A., STEINER, J. L., KRIEG, D. R., SCHNEIDER, A. D. 1995. Role of transpiration suppression by evaporation of intercepted water in improving irrigation efficiency. *Irrig. Sci.*, 16: 89–95.

TRNKA, M., SCHAUMBERGER, A., FORMAYER, H., EITZINGER, J., HLAVINKA, P., SEMERÁDOVÁ, D., DUBROVSKÝ, M., MOŽNÝ, M., THALER, S., ŽALUD, Z. 2011. Evaluating drought risk for permanent grasslands under present and future climate conditions. *Procedia Environ. Sci.*, 3: 50–57.

WATSON, D. J. 1947. Comparative Physiological Studies on the Growth of Field Crops: I. Variation in Net Assimilation Rate and Leaf Area between Species and Varieties, and within and between Years. *Ann. Bot.* 11: 41–76.

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