Effect of soil moisture on evapotranspiration of a maize stand during one growing season

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A b s t r a c t : The cumulative evapotranspiration of a maize stand was determined during the growing season over the period of 148 days from planting to the stage of the full ripeness. The total evapotranspiration in this time interval was 276.4 mm while the amount of precipitation reached in the analysed period 295.4 mm. The transpiration and soil evaporation daily courses were calculated using a verified mathematical model of interrelationships existing within the system soil-plants-atmosphere. In the vegetation period 2000 the investigated maize stand transpirated under changing environmental conditions. It was found that the soil water availability practically did not affect the evapotranspiration when at least 58.2% of extractable soil water was present in the root zone, but below this value, the evapotranspiration decreased linearly with the decrease in the soil water content. During the analysed period, the reduction of evapotranspiration caused by shortage of soil water has been partially compensated by the high evaporative demands of the air, so that the daily totals of evapotranspiration remained relatively high.

Key words: maize, soil moisture, evapotranspiration, atmospheric factors

1. Introduction

The daily transpiration accumulated over a given time interval usually determines the biomass production for that interval in a given climate

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(*de Witt, 1958; Tanner and Sinclair, 1983*). Consequently, one of the most common limiting environmental factors for plant growth is water supply (*Steduto and Hsiao, 1998b*). Evapotranspiration is a crucial parameter in most crop yield forecasting models. The quantity of water losses by evapotranspiration must be known for correct irrigation scheduling (*Rana et al., 1997*). For these reasons, estimations of the evapotranspiration have been recognized as important from many theoretical and practical aspects. Respecting this fact, the evapotranspiration of various field crops was frequently a subject of research. Nevertheless, most of these publications are short term studies covering the time interval of a few days to several weeks (*Hatfield et al., 1984; Choudhury et al., 1986; Bastiaanssen et al., 1997; Kjelgaard et al., 1994*). Till now, only a few authors analyzed the evapotranspiration over a major part of the vegetation period (*Baldocchi et al., 1981; McGinn and King, 1990; Steduto and Hsiao 1998a, 1998b*). Besides, the results based on experimental data are valid only for the geographic and climatic conditions where they were obtained, so that a generalization is difficult, or quite impossible. Therefore the further investigation on this topic in different soil, geographic and climatic conditions is needed. Thus, the aim of this study is to quantify the response of evapotranspiration from a maize stand to changes in soil moisture in environmental conditions of the south-east part of the Czech Republic.

2. Material and methods

The experimental data used for determination of the evapotranspiration and its components were obtained at an experimental site of the Agricultural School Enterprise at Žabčice (latitude 49° 01′ N, longitude 16° 37′ E and 179 m above the see level) serving as the research basis of the Mendel University of Agriculture and Forestry in Brno (Czech Republic). The experimental site Žabčice is located in a warm microclimatological region with a predominantly moderate winter. The region is the driest in the Czech Republic, whereby the mean annual sum of precipitation is 480 mm. The soil is classified as Gleyic Fluvisol. The soil is deep and relatively homogeneous. The mean values of the retention field capacity and of the wilting point in the root zone are 38% by volume and 21% by volume, respectively (*Šťastná* *and Žalud, 1999; Eitzinger et al., 2003*). The groundwater table was at a depth of about 1.8 m and its influence on the plant water regime can be considered as negligible. The field was not irrigated, so the atmospheric precipitation represents the only water resource. A field of 0.5 ha was planted with maize (*Zea mays* L.), the variety "STIRA", having the plant density of 12 plants/m^2 and row spacing of 0.7 m.

The microclimatic profile measurements of the wind speed, the air temperature and relative humidity were carried out at this experimental site during the whole vegetation period. Soil water content profiles in the root zone were determined gravimetrically. Also daily totals of precipitation were available. The detailed description of the experimental stand and microclimatic measurements were published earlier (*Matejka et al., 2004*).

The weekly sums of the actual evapotranspiration were determined according to the water balance method (*Novák, 1995*) over the period from May to September 2000. The values of weekly sums of the evapotranspiration were obtained by balancing precipitation, interception, water uptake by roots from the soil layer with depth 0 – 60 cm and soil evaporation to obtain weekly sums of the evapotranspiration.

To calculate daily courses of evapotranspiration and its components, a mathematical model of interrelationships existing within the soil-plants-atmosphere system was used (*Huzulák and Matejka, 1989a, 1989b; Huzulák and Matejka, 1996*). The simulation model was constructed in accordance with interactions existing between the stand canopy and the boundary layer of the atmosphere (*Bichele et al., 1980*). Input data of this model involved soil parameters, biometric characteristics of the stand, and meteorological elements as global radiation, wind speed, air temperature and air humidity at one level above the stand. The output of this model provides values of the evapotranspiration and its components.

The model was verified in different soil and climatic conditions for different stands. The verification carried out for a maize stand showed that the model is able to simulate daily courses of evapotranspiration quite realistically with acceptable accuracy (*Matejka, 1995*).

3. Results and discussion

The seasonal changes in evapotranspiration were determined from planting to the stage of the full ripeness over the period 4th May - 28th September 2000. The total evapotranspiration in the analysed period of 148 days reached 276.4 mm while the total amount of precipitation during the same time interval was 295.4 mm. For the whole analyzed period, the mean daily sum of the evapotranspiration was 1.87 mm/day. Daily totals of evapotranspiration from the field with maize reported by other authors are a little greater, particularly 4.2 mm/day (*Jara et al., 1998*), or 4.67 mm/day (*Kjelgaard et al., 1994*). However, these mean values were averaged over shorter periods (64 days and 57 days, respectively). In these periods, the canopy was closed and values of the green leaf area index were high. It is obvious, that the mean daily total of evapotranspiration at Žabčice averaged over the period of 148 days, where the phase of senescence is included, must be lower in comparison with data of quoted authors. The gradual increase in the cumulative evapotranspiration, obtained by the water budget method balancing evapotranspiration, precipitation, interception and changes in the soil water content in the root zone, is graphically presented in Fig. 1. It

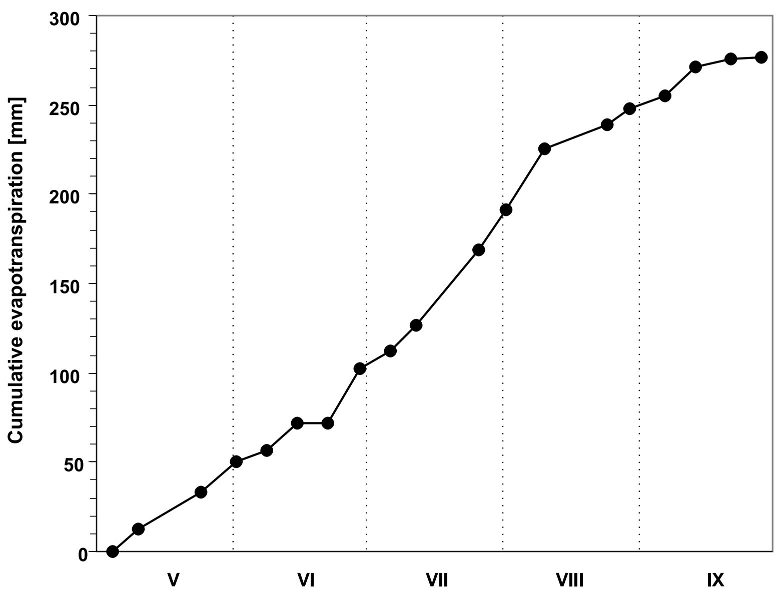

Fig. 1. The cumulative evapotranspiration of the maize stand from planting to the stage of full ripeness determined according to the water balance method over the growing period of the year 2000.

can be seen from Fig. 1 that the highest evapotranspiration rates occurred in the first half of August when the soil was relatively wet and the canopy was fully closed.

Besides the soil and plant characteristics, the actual evapotranspiration depends on meteorological conditions. Respecting this fact, the sets of clear days and cloudy days were selected from the analysed vegetation period 2000 and the both sets were analysed separately. Daily totals and extremes of the global radiation and daily means and extremes of air temperature and vapour pressure deficit for both data sets are presented in Tab. 1 and 2, respectively.

Differences in daily totals of evapotranspiration and seasonal changes in its structure are obvious from Tabs 3 and 4. The mean daily total of evapotranspiration in clear days was 2.55 mm/day while for the cloudy days the mean daily total of evapotranspiration dropped to 0.31 mm/day. This data are comparable with the corresponding results obtained earlier in the locality with similar climatic conditions (*Hurtalová, 1990*).

During the analysed growing period of the year 2000, the values of soil moisture in the root zone varied significantly as a result of high evaporative demands of the atmosphere and the non-uniform time distribution of the precipitation (Fig. 2). Consequently, it provides a possibility to analyse and quantify the response of evapotranspiration to changes in soil moisture. With this aim, the hourly sums of the actual evapotranspiration were calculated using the mathematical model of the plant water regime (*Huzulák and Matejka, 1989a,b; Huzulák and Matejka, 1996*).

Simultaneously, the potential evapotranspiration was determined with a time step of one hour according to the Penman method (*Penman, 1948*) as it was modified later (*Allen et al., 1989; Smith et al., 1991*). Then, daily totals of the actual and potential evapotranspiration were calculated. To separate the influence of atmospheric factors on evapotranspiration rates, the relative evapotranspiration, defined as the ratio between actual and potential evapotranspiration, on the soil moisture was analysed. The relationship between the ratio of the actual/potential evapotranspiration and soil moisture is presented in Fig. 3 together with a fitting logistic function. The interpretation of the dependence presented in Fig. 3 can be based on the frequently used simplified conception (*Denmead and Shaw, 1962; Feddes et al., 1988; Novák, 1995*), which assumes that the actual evapotranspira-

Tab. 1. Daily totals and maximums of the global radiation and the daily means and extremes of air temperature and vapour pressure deficit for the selected clear days at height of 2 m above the zero plane displacement level

CLEAR DAYS	Global radiation		Air temperature			Vapour pressure deficit		
	Sum [MJ m^{-2}]	Max. [W m^{-2}]	Mean [°C]	Max. [°C]	Min. [°C]	Mean [hPa]	Max. [hPa]	Min. [hPa]
15/5	28.24	881	20.1	29.7	8.9	15.81	33.14	2.17
27/5	27.71	883	21.1	30.9	13.2	13.84	32.52	0.68
20/6	30.04	909	24.1	34.5	10.6	20.07	42.47	1.18
21/6	29.56	901	26.3	37.0	13.3	23.87	43.94	2.55
23/7	25.55	903	20.4	28.2	12.8	8.99	23.55	0.06
24/7	18.97	862	21.5	28.8	14.1	8.11	20.06	0.42
13/8	23.23	796	24.6	32.5	18.4	13.93	31.90	4.32
20/8	22.12	753	25.9	35.8	17.4	14.43	37.53	0.69
21/8	22.11	771	26.1	35.2	17.4	16.61	39.85	0.89
10/9	19.45	720	15.7	25.6	7.3	7.44	21.45	0.00
29/9	14.78	605	15.9	22.0	9.7	8.63	16.63	0.23
30/9	14.53	594	17.3	22.6	13.0	8.42	14.68	4.29

Tab. 2. Daily totals and maximums of the global radiation and the daily means and extremes of air temperature and vapour pressure deficit for the selected cloudy days at height of 2 m above the zero plane displacement level

CLOUDY DAYS	Global radiation		Air temperature			Vapour pressure deficit		
	Sum [MJ m^{-2}]	Max. [W m^{-2}]	Mean [°C]	Max. [°C]	Min. [°C]	Mean [hPa]	Max. [hPa]	Min. [hPa]
19/5	9.84	558	13.1	17.8	7.7	2.81	8.82	0.11
24/6	11.92	579	18.4	24.8	12.8	6.84	19.72	0.34
25/6	10.54	526	14.3	19.6	8.6	2.67	9.13	0.13
11/7	4.73	230	15.6	19.1	10.5	2.07	7.31	0.01
16/7	4.43	133	13.2	14.2	12.2	1.32	2.71	0.03
31/8	4.18	244	17.0	20.0	14.3	2.87	7.20	0.27
20/9	3.98	258	11.2	13.2	9.3	1.65	2.83	0.38
21/9	3.59	422	11.8	14.7	10.5	2.18	4.43	0.23
8/10	2.09	118	10.6	11.6	9.5	0.73	1.58	0.00

tion of dense plant canopies, sufficiently supplied with water, equals the potential evapotranspiration.

When the soil water content drops below a threshold value W_t, the ratio between the actual and potential evapotranspiration decreases linearly until

Tab. 3. Daily totals of transpiration ET, soil evaporation ES and evapotranspiration E during the clear days

Clear days	15/5	27/5	20/6	21/6	23/7	24/7	13/8	20/8	21/8	10/9	29/9	30/9
ET [mm/day]	0.01	0.01	2.61	2.74	1.88	1.60	1.97	1.57	1.52	0.08	0.01	0.01
ES [mm/day]	2.58	3.13	1.60	1.75	0.79	0.65	0.89	1.54	1.40	1.10	0.61	0.52
E [mm/day]	2.59	3.14	4.21	4.49	2.67	2.25	2.87	3.11	2.91	1.18	0.62	0.53
ET/E	0.00	0.00	0.62	0.61	0.70	0.71	0.69	0.51	0.52	0.07	0.01	0.02
ES/E	1.00	1.00	0.38	0.39	0.30	0.29	0.31	0.49	0.48	0.93	0.98	0.98
ET/ES	0.00	0.00	1.63	1.56	2.39	2.48	2.20	1.02	1.09	0.07	0.01	0.02

Tab. 4. Daily totals of transpiration ET, soil evaporation ES and evapotranspiration E during the cloudy days

Cloudy days	19/5	24/6	25/6	11/7	16/7	31/8	20/9	21/9	8/10
ET [mm/day]	0.00	1.07	0.74	0.46	0.36	0.15	0.00	0.00	0.00
ES [mm/day]	1.17	0.39	0.21	0.11	0.09	0.32	0.28	0.28	0.20
E [mm/day]	1.18	1.46	0.95	0.57	0.45	0.47	0.28	0.28	0.20
ET/E	0.00	0.74	0.78	0.81	0.80	0.32	0.00	0.00	0.00
ES/E	1.00	0.26	0.22	0.19	0.19	0.68	1.00	1.00	1.00
ET/ES	0.00	2.79	3.59	4.21	4.16	0.47	0.00	0.00	0.00

the soil water content approaches the wilting point. It follows from Fig. 3 that the threshold value of soil moisture for the analyzed maize field was about 29% of volume. Expressing soil water content in the root zone as the amount of available water for plants, this threshold value of soil moisture corresponds to 58.2% of available water.

4. Conclusion

In the vegetation period 2000, the investigated maize stand transpirated under changing environmental conditions and under the significant decrease in soil moisture recorded at the end of June. It was found that the soil water availability practically did not affect the evapotranspiration when at least 58.2% of extractable soil water was present in the root zone, but below this value, the evapotranspiration decreased linearly with the decrease in the soil

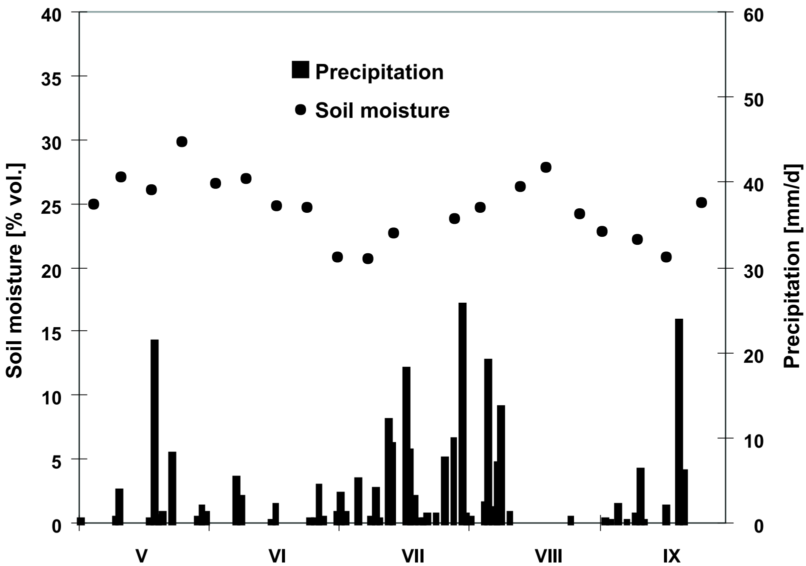

Fig. 2. Mean soil moisture in the soil layer 0 – 60 cm and daily totals of precipitation over the growing period of the year 2000.

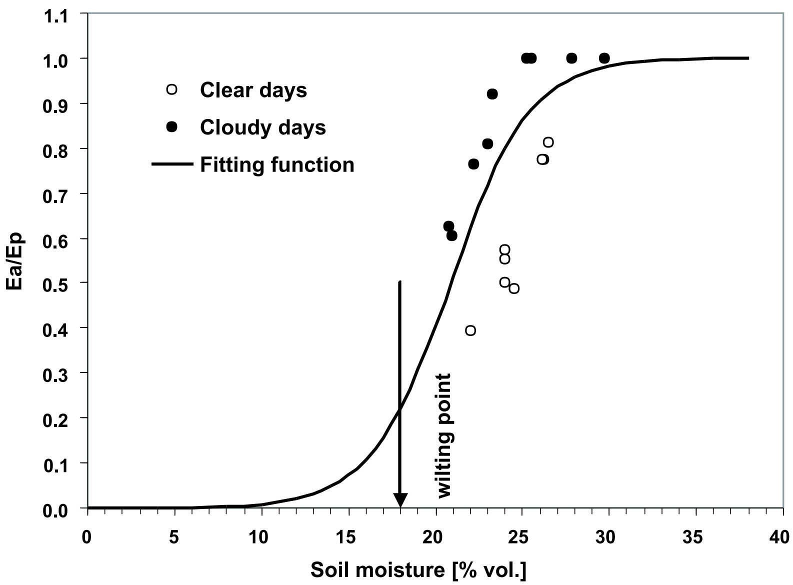

Fig. 3. The dependence of the ratio between the actual and potential evapotranspiration Ea/Ep on mean soil moisture in the soil layer 0 – 60 cm.

water content. When the amount of available water for plants approaches the wilting point, the actual evapotranspiration is negligible.

The soil drought was accompanied by very dry air which occurred especially in the last decade of June. Nevertheless, the reduction of the evapotranspiration caused by the shortage of soil water was compensated by the low air humidity having as a result high evaporative demands of the atmosphere. Consequently, daily totals of evapotranspiration remained sufficiently high even in the periods of soil drought.

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