PHOTOSYNTHESIS PARAMETERS AND WATER USE EFFICIENCY IN RELATION TO THE WATER SUPPLY IN MAIZE (ZEA MAYS L.)

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Abstract

Measurement series have been applied to maize experiments in 4 very different water state years (2010-2013) to evaluate the water use efficiency in relation with the photosynthetic activity. Fertilizer levels were: N60P45K45 kg per hectare.

The soil of the experimental area is calciferous chernozem, with sediments of around 50%, with somewhat lower values in the lower layers (41-45%). The thickness of the humus stratum is around 0.70-0.80 m. The humus content of the evenly humidified layer is 2.5-3.4 %.

Assimilation parameters were measured in the field by the LICOR LI-6400 portable photosynthesis system. It has two infrared gas analyzers to measure CO_2 and H_2O mole fraction in air. Light changes will cause immediate photosynthetic rate changes therefore the light was controlled in the sample chamber. We used 2000 μmol photon m^{-2} s^{-1} PAR, with 90 % red (630 nm) and 10 % blue (470 nm) light. There is a contact thermometer in the leaf chamber to measure leaf temperature. We measured light adapted leaves, six times per leaf, in four repetitions.

The results obtained suggest, that the water use efficiency of the maize is higher in dry years. In wet year (2010) maize uses up to 260 per cent more water for 1 g CO_2 assimilation. The efficiency of the CO_2 assimilation varies in the involved 4 years greatly, with 350 per cent. The highest efficiency value we calculated was 8.45 per cent in 2012 year.

Key words: maize, soil moisture, photosynthesis, transpiration.

INTRODUCTION

Several researchers studied the factors have effect on the photosynthesis system of maize (Raschke, 1970; Lu, Zhang, 2000; Hirashawa, 1999; Kutasy, Csajbók, 2009; Csajbók, Kutasy, 2012). Shangguan et al. (2000) did researches regarding to the relationships between nitrogen supply, the water supply and the photosynthetic gas exchange parameters. They wrote that the nutrient and water supply has significant effect on the photosynthetic gas exchange of the plant. The better nitrogen supply results in poorer water use efficiency comparing to the lower nitrogen supply conditions, due to the high rate decreasing in photosynthetic activity. Hagyó et al. (2007) analyzed the response of different wheat genotypes on water stress. They found differences between reactions of genotypes.

Janda et al. (1998) studied the effect of temperature in the growing period on the net photosynthesis rate of inbred maize lines. They found that at optimal temperature there were no significant differences between the maize lines in the net photosynthesis rate, but after cold treatment the net photosynthesis rate of the lines with lower cold tolerance reduced significantly.

Kang et al. (2000) did two years study on the effect of water stress on the photosynthesis rate of maize leaf. They stated that the reduced photosynthesis of the water-stressed leaf recovered its previous level three days after irrigation applied. Ben-Asher et al. (2008) studied the transpiration and photosynthetic activity of sweet corn in climate chamber. Their results show that increasing of temperature causes higher transpiration and decreasing in the photosynthesis intensity (with 1 μmol m^{-2} s^{-1} by 1 °C temperature increasing).

MATERIAL AND METHOD

The observation was carried out at the Látókép Plant Cultivation Research Site of the Centre for Agricultural and Applied Economic Sciences, University of Debrecen, in 2010-2013. The maize hybrid was PR37N01 and the applied fertilizer dose was N120, P75, K90 kg ha^{-1}. The precipitation of growing season (April-September) varied greatly in the analyzed years, in 2010 it was 590 mm, in 2011 314 mm, in 2012 262 mm and in 2013 it was 254 mm.

The soil of the experimental area is calciferous chernozem. Its physical characteristics are that of semi compacted clay category. The thickness of the humus stratum is around 70-80 of which the evenly humidified stratum is about 40-50 cm thick. The humus content of the evenly humidified layer is 2.5-3.4 %. The soil specific plasticity index (KA) was 43, the pH value was nearly neutral (pH_{KCl}=6.46). The phosphorus content of the soil was medium (the value of AL-soluble P_2O_5 was 133 mg kg^{-1}), the degree of potassium supply was fairly-good (the value of AL-soluble K_2O was 240 mg kg^{-1}).

Examining the water conditions of the soil, it can be stated, that it is typical to the chernozem soils, i.e. has favorable water regime, excellent water holding capacity (808 mm in the 0-200 cm layer), unavailable water content is 295 mm in the 0-200 cm layer, the amount of disponible water in saturated state is 513 mm in the 0-200 cm layer of which 342 is readily available. The watertable is at 8-10 meters depth.

Assimilation parameters were measured in the field with a LICOR 6400 portable photosynthesis system. We measured the leaf net CO_2 assimilation rate, stomatal conductance, intercellular CO_2 level, the transpiration, the leaf temperature and the air temperature, air pressure. The light was controlled and stable in the sample chamber. We used 2000 □mol photon m^{-2} s^{-1} photosynthetic active radiation (PAR) with 90 % red (630 nm) and 10 % blue (470 nm) light. We measured six times per leaf, in four repetitions.

We have determined the potential evapotranspiration (PET) with a calculation taking days into account according to the method of Gábor Szász (1988). This method takes into account those atmospherical factors and processes that decisively effect the evaporation of water. (average daily temperature (°C), saturation ratio (e/E), coefficient of oasis effect, impact function of wind (f(v)). The actual evapotranspiration (AET) has also been determined according to calculation based on daily data according to the Emanuel Antal formula. The method takes into consideration the water absorbing capacity of the atmosphere, the water content of the soil and the effects of plants. Data required: relative humidity in the root zone (mm), a coefficient allowing for the effects of plants, value of potential daily evapotranspiration (mm day^{-1}). I have used a 20 cm layer in the beginning of the calculations and increased the depth of the root zone with 20 cm in every 14 days till I have reached 1 meter depth.

The water use efficiency parameters were calculated from the measured data (WUE g CO_2 kg^{-1} H_2O) and (1/WUE kg H_2O kg^{-1} CO_2).

We analyzed and evaluated the data of experimental results with the SPSS 17.0 statistical software package. The accuracy of the statistical analysis were given at the level of LSD5% according to the method of Sváb (1981). The results were evaluated with analysis of variance, and Pearson's correlation analysis.

RESULTS AND DISCUSSION

The water supply in the growing season was the best in 2010 (AET was 88 % of PET) and the worst in 2012 (AET:PET ratio was 37%) as it clearly show Figures 1-4. In 2013 the first half of the growing season was favourable regarding to water supply, but from July it was very dry, and the AET:PET ratio was only 27,5% in August.

The water use efficiency was lower (23.33 g CO_2 kg^{-1} H_2O) in the wet year 2010, than in 2011 (52.88 g CO_2 kg^{-1} H_2O), in 2012 (36.19 g CO_2 kg^{-1} H_2O) or in 2013 (61.52 g CO_2 kg^{-1} H_2O). The maize incorporated in average 61.52 g CO_2 while transpirated 1 liter water in 2013.

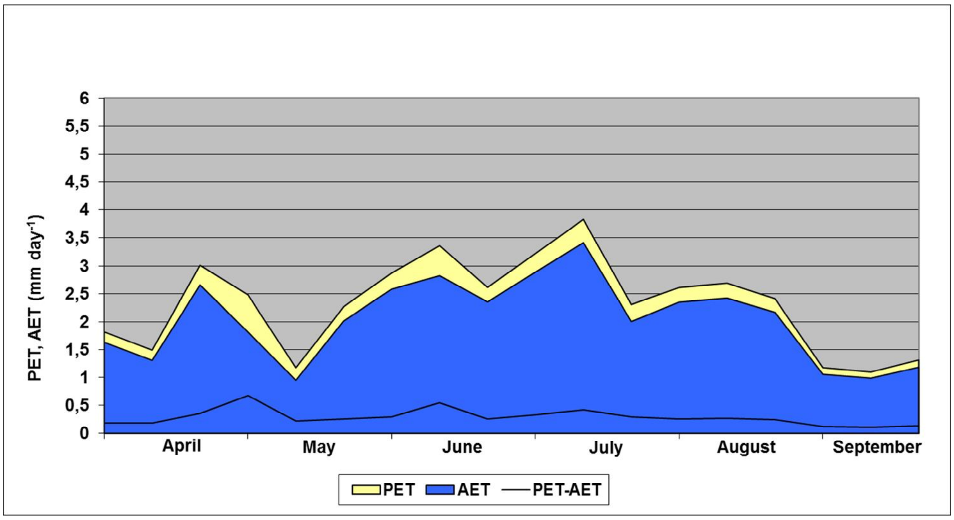

Fig. 1. The estimated potential (PET) and actual evapotranspiration (AET) values and the difference between them in maize (Debrecen, 2010)

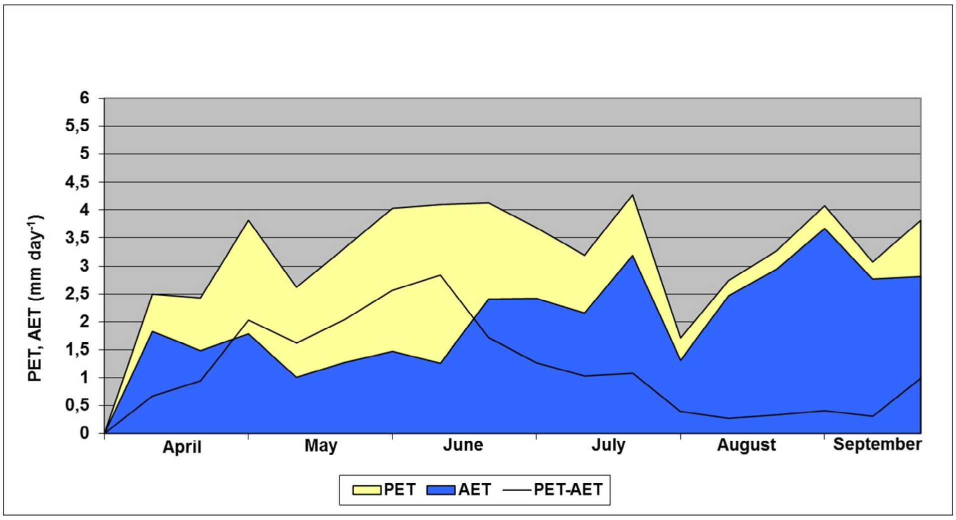

Fig. 2. The estimated potential (PET) and actual evapotranspiration (AET) values and the difference between them in maize (Debrecen, 2011)

We also studied the relations between the transpiration and the different measured parameters of the photosynthesis. The correlation coefficient values (r) between net photosynthesis rate and the transpiration varied from 0.596 to 0.715 in 2010-2013. Between the stomatal conductance and the transpiration we found significant correlation, the r values were 0.97-0.998 (Table 1). We calculated the linear regression functions regarding to reveal the relationships between the photosynthesis intensity and transpiration in 2010-2012. The connection was the best in 2011.

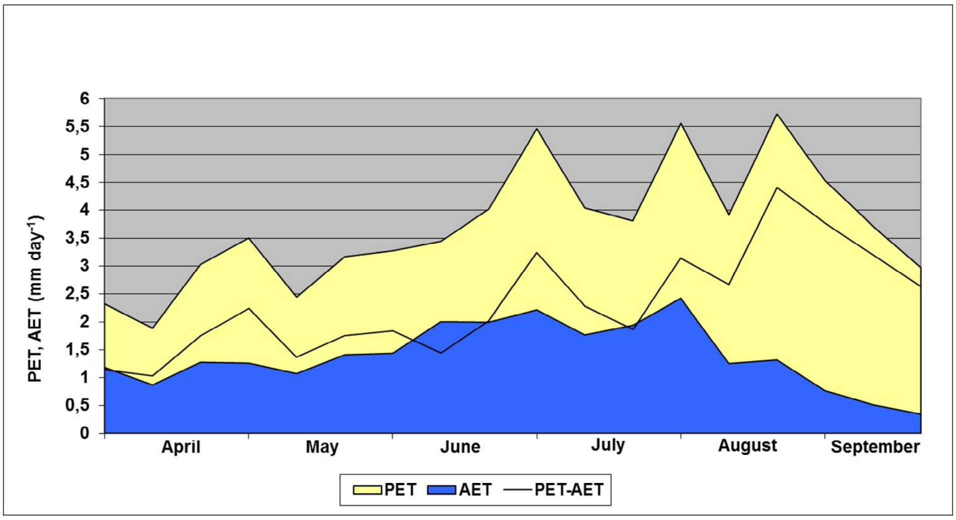

Fig. 3. The estimated potential (PET) and actual evapotranspiration (AET) values and the difference between them in maize (Debrecen, 2012)

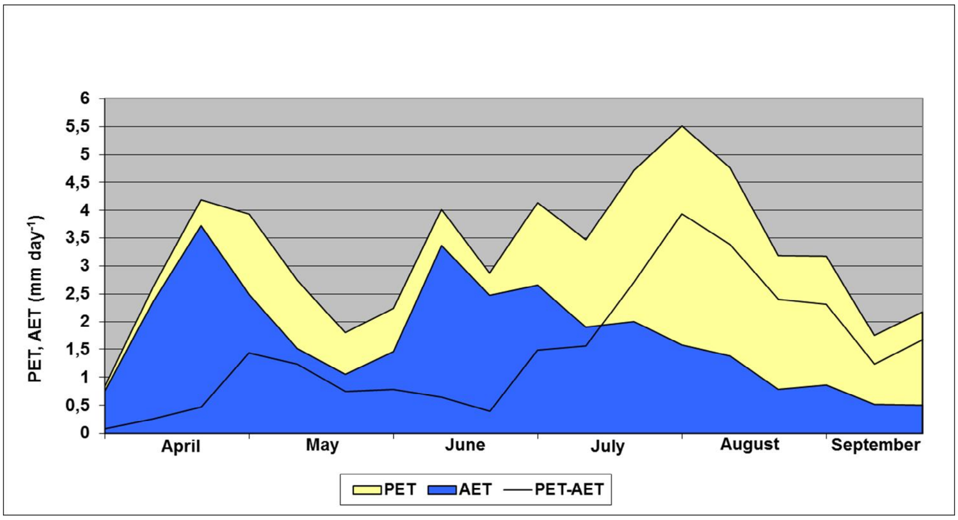

Fig. 4. The estimated potential (PET) and actual evapotranspiration (AET) values and the difference between them in maize (Debrecen, 2013)

We calculated the linear regression functions regarding to reveal the relationships between the photosynthesis intensity and transpiration in 2010-2013. The connection was the best in 2011.

The difference between the air and leaf temperature shows well the plant can cool its leaves by transpiration, or not. The cooling effect of transpiration was weak in 2012 and 2013 the temperature of the leaves were only by 0.24 °C and 0.41 °C lower than that of air in average. These data show severe water stress condition in 2012 and 2013. The average of difference was 2.11 °C in 2011 and 2.56 °C in 2010. The correlation coefficient value varies from 0.669 to 0.832 in single years (Figure 5).

The average of CO_2 assimilation efficiency was 4.22% in 2010, 8.45% in 2011, 2.41% in 2012 and 3.76% in 2013. According to the data of the measurements we have taken in maize from 1999 the efficiency was expected between 3-5%, so the results in 2010 and also in 2012 were outliers.

Table 1

Correlations between the transpiration, the water use efficiency and the measured photosynthesis parameters of maize (r values of Pearson correlation) (Látókép, 17 07 2011)

	Photo	**Cond**	**Ci**	**ΦCO_2**	**Trmmol**	**1/WUE**	**tair-tleaf**
Photo(1)	1	0,587	-0,098	0,999	0,596	0,668	0,694
Cond(2)	0,587	1	-0,096	0,582	0,998	0,934	0,804
Ci(3)	-0,098	-0,096	1	-0,098	-0,095	-0,071	-0,113
ΦCO_2(4)	0,999	0,582	-0,098	1	0,591	0,663	0,689
Trmmol(5)	0,596	0,998	-0,095	0,591	1	0,937	0,801
1/WUE(6)	0,668	0,934	-0,071	0,663	0,937	1	0,822
tair-tleaf(7)	0,694	0,804	-0,113	0,689	0,801	0,822	1

1: net photosynthesis rate (μmol CO_2 m^{-2} s^{-1}), 2: stomatal conductance (mol H_2O m^{-2} s^{-1}), 3: intercellular CO_2 level (μmol CO_2 m^{-2} s^{-1}), 4: CO_2 fixing efficiency (%), 5: transpiration (mmol H_2O m^{-2} s^{-1}), 6: water use efficiency (kg H_2O $g^{-1}CO_2$), 7: air temperature – leaf temperature (°C)

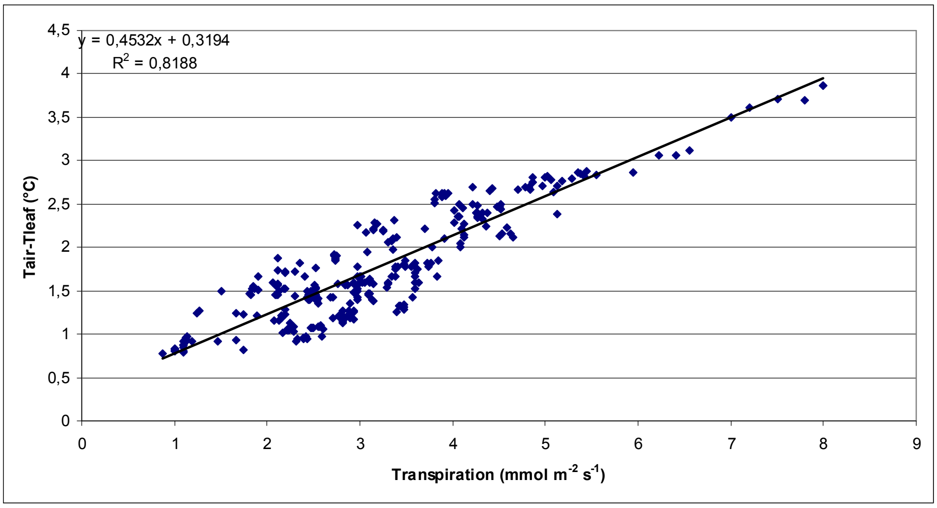

Fig. 5. Connections between the difference of air and leaf temperatures and the transpiration rate in maize (Látókép, 31 07 2012)

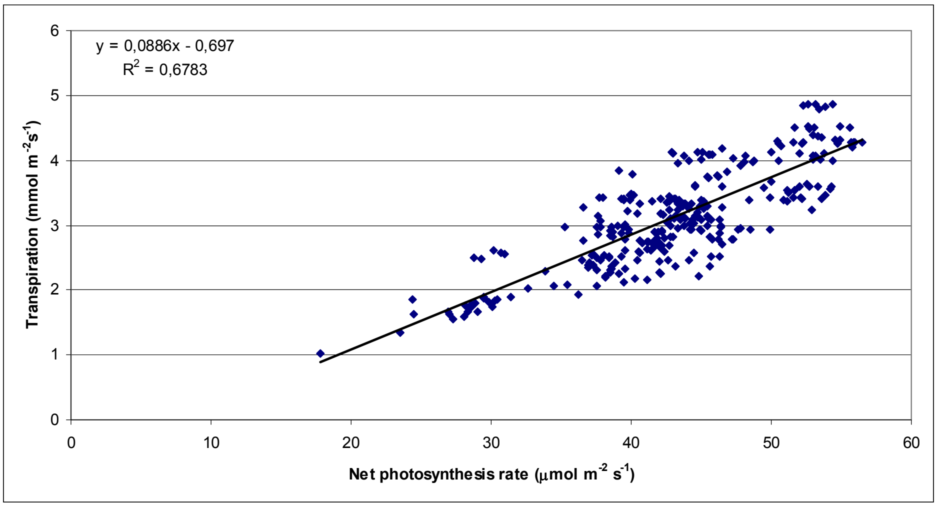

Fig. 6. The transpiration in the function of photosynthesis intensity in maize (Látókép, 17 07 2011)

CONCLUSIONS

We can state as the result of the measurements in three years with remarkably different water supply that maize use water with much less efficiency under favorable water supplying conditions than in dry years. Maize transpirates 150-260% more water to one gram CO_2 assimilation than in dry years or in water stress. We found strong positive significant correlations in maize between the net photosynthesis rate and the transpiration, the transpiration and the difference of air and leaf temperatures. The stomatal conductance and the transpiration as well as the water use efficiency have also very strong positive significant correlations.

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