THE WATER USE EFFICIENCY OF MAIZE DEPENDING ON ABIOTIC STRESS FACTORS IN FIELD EXPERIMENTS

József CSAJBÓK – Erika KUTASY –Péter PEPÓ

Institute of Crop Sciences, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, H-4032 Debrecen, Böszörményi út 138, e-mail: csj@agr.unideb.hu

Abstract

There is little direct information about the effects of the abiotic stress factors such as low soil water content on the photosynthesis system of field crops. Some recent publications pay attention to this field of research. Water stress has significant effect on the yield and other agronomic parameters of maize. The aim of our work was to get more data about the relations between water supply and the assimilation parameters. The photosynthetic gas exchange parameters of maize are remarkably improved by nutrient supply in well watered conditions. The water stress through decreased stomatal conductance has significant negative effect on the assimilation parameters of the crops. The obtained results suggest that the water use efficiency of the maize is higher in dry conditions. In well water supply state maize uses up to 300 per cent more water for 1 g CO_2 assimilation.

Keywords: maize, water use efficiency, abiotic stress

Introduction

There are some articles dealing with photosynthesis system and the water use efficiency topics of maize published in the last decades (Raschke, 1970, Lu and Zhang, 2000, Hirashawa, 1999, Kutasy and Csajbók, 2009, Csajbók and Kutasy, 2012). Shangguan et al. (2000) 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. 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) implemented a 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 climatic chambers. Their results show that increasing temperature causes higher transpiration and decrease the photosynthesis intensity (with 1 µmol m^{-2} s^{-1} by 1 °C temperature increasing).

Materials and methods

The measurements were carried out between 1999 and 2013 at the Látókép research site of the Debrecen University in small plot (15.4 m^2) experiments. The soil of the experimental area is calciferous chernozem. The soil specific plasticity index (KA) was 43; the pH value was nearly neutral (pH_{KCl}=6.46) and it has favourable water regime. The minimal water storing capacity is 808 mm in the 0-200 cm layer. The unavailable water content is 295 m in the 0-200 cm layer. The amount of available water in saturated state is 513 mm in the 0-200 cm layer of which 342 mm is readily available. The watertable is at 8-10 meters depth.
The set crop rotations: triculture (winter wheat – maize – pea), biculture (winter wheat – maize), monoculture: maize.

Fertilization levels:
control: $N_0P_0K_0$, $N_{120}P_{90}K_{90}$ kg ha^{-1}

Assimilation parameters were measured in the field by the LICOR LI-6400 portable photosynthesis device.

It has two infrared gas analyzers to measure CO_2 and H_2O mole fraction in air. 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 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 22.0 statistical software package. The accuracy of the statistical analysis was given at the level of $LSD_{5\%}$ according to the method of Sváb (1981). The results were evaluated with analysis of variance, and Pearson's correlation analysis.

Results and discussion

To present the water supply state of maize in the studied years we calculated the potential (PET) and actual evapo-transpiration (AET) (Szász, 1997) and their ratio. 2000, 2002, 2007, 2009, 2012 were very dry years, the PET:AET ratio was very low in these growing seasons. On the contrary the water supply in 2004, 2005,

Figure 1. Estimated PET and AET values, PET:AET ratio and the precipitation in maize growing season (Látókép, 1999-2013)

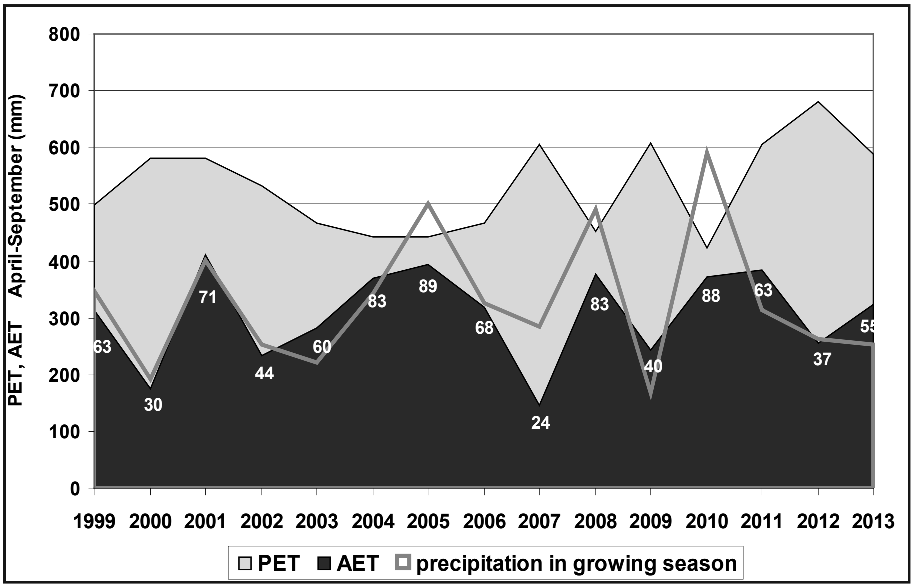


Figure 2. The estimated potential (PET) and actual evapotranspiration (AET) values and the difference between them in maize (Látókép, 2013)

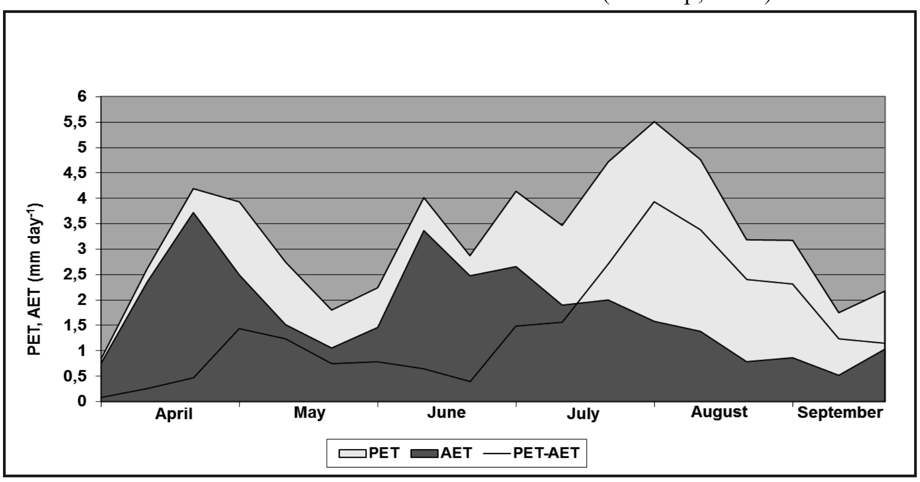


Table 1 Correlations between the transpiration, the water use efficiency and the measured photosynthesis parameters of maize (r values of Pearson correlation) (Látókép, 04 07 2013)

		Cond	Trmmol	1/WUE	tair-tleaf
Monoculture	Cond(1)	1	0.990	-0.949	0.689
	Trmmol(2)	0.990	1	-0.950	0.599
	1/WUE(3)	-0.949	-0.950	1	-0.638
	tair-tleaf(4)	0.689	0.599	-0.638	1
Biculture	Cond(1)	1	0,971	-0.900	0.761
	Trmmol(2)	0,971	1	-0.935	0.598
	1/WUE(3)	-0.900	-0.935	1	-0.544
	tair-tleaf(4)	0.761	0.598	-0.544	1
Triculture	Cond(1)	1	0.980	-0.948	0.800
	Trmmol(2)	0.980	1	-0.961	0.683
	1/WUE(3)	-0.948	-0.961	1	-0.654
	tair-tleaf(4)	0.800	0.683	-0.654	1

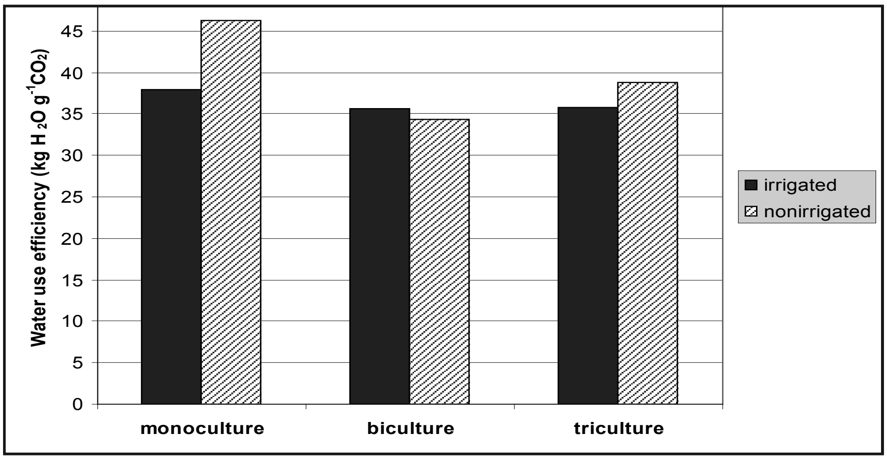
1: stomatal conductance (mol H_2O m^{-2} s^{-1}), 2: transpiration (mmol H_2O m^{-2} s^{-1}), 3: water use efficiency (kg H_2O $g^{-1}CO_2$), 4: air temperature – leaf temperature (°C). The correlation coefficient values are significant at P=5% level in every above cases.

2008 and 2010 was very good to maize (Figure 1). 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 (Figure 2).

We did analysis of water use efficiency of maize in different crop rotation varieties. Analyzing the assimilated CO2 value pro one liter transpired water is a useful method of characterizing the water use efficiency of the crops. Our data show that there are significant strong positive correlation between stomatal conductance and transpiration, significant strong negative correlation between transpiration and water use efficiency in every crop rotation variations (Table 1). The difference between air and leaf temperature shows significant positive correlations to the transpiration and the stomatal conductance and negative correlation to the water use efficiency.

The water use efficiency was higher in 2013 (38.14 g CO_2 kg^{-1} H_2O) than that of in wet 2010 (23.33 g CO_2 kg^{-1} H_2O). There were significant differences between the crop rotation varieties, monoculture: 42.09 g CO_2 kg^{-1} H_2O, biculture: 35.01 g CO_2 kg^{-1} H_2O and the triculture: 37.31 g CO_2 kg^{-1} H_2O ($LSD_{5\%}$=1.09). As monoculture means unfavourable water supply comparing to the biculture, this data

Figure 3 Water use efficiency of maize in different crop rotation variations (Látókép, 2013)



coincide with results of our previous researches under remarkably different water supply showing that maize use water with much less efficiency under favourable water supplying conditions than in dry years. Maize transpires 150-260% more water to one gram CO_2 assimilation than in dry years or in water stress (Figure 3). The irrigation had significant effect on the water use efficiency of maize in the experiment. The greatest effect we measured in monoculture (non irrigated: 46.27 g CO_2 kg^{-1} H_2O, irrigated: 37.91 g CO_2 kg^{-1} H_2O). The better water supply caused significantly lower efficiency in water use.The difference was lower in the triculture rotation (non irrigated: 38.84 g CO_2 kg^{-1} H_2O, irrigated: 35.62 g CO_2 kg^{-1} H_2O) and the lowest difference was in the biculture variation in water use efficiency (non irrigated: 34.39 g CO_2 kg^{-1} H_2O, irrigated: 35.62 g CO_2 kg-1 H_2O).

We also made measurements in experiments on nutrient supply relating to the water use of maize. In 2003 the plants in control plots transpired more water to assimilate 1 g CO_2 as did the plants in fertilized plots in the first 3 measurement dates (Figure 4). The adequate nutrient supply increased the efficiency of water use of maize. At the fourth

Figure 4. Effect of nutrient supply on the water use efficiency of maize (Debrecen, 2003)

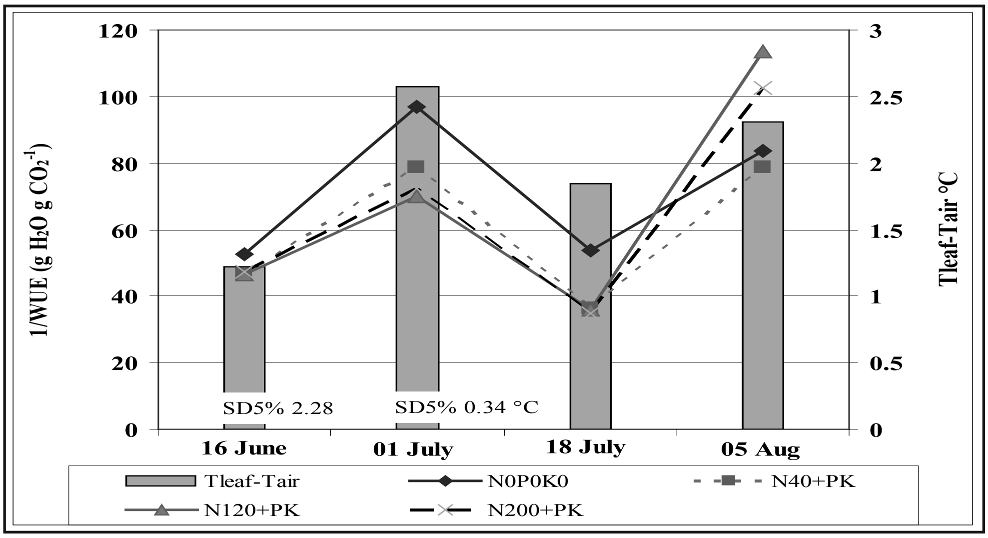


Figure 5. The effect of light intensity on the water use efficiency of maize, wheat and some weeds (Látókép, 2004)

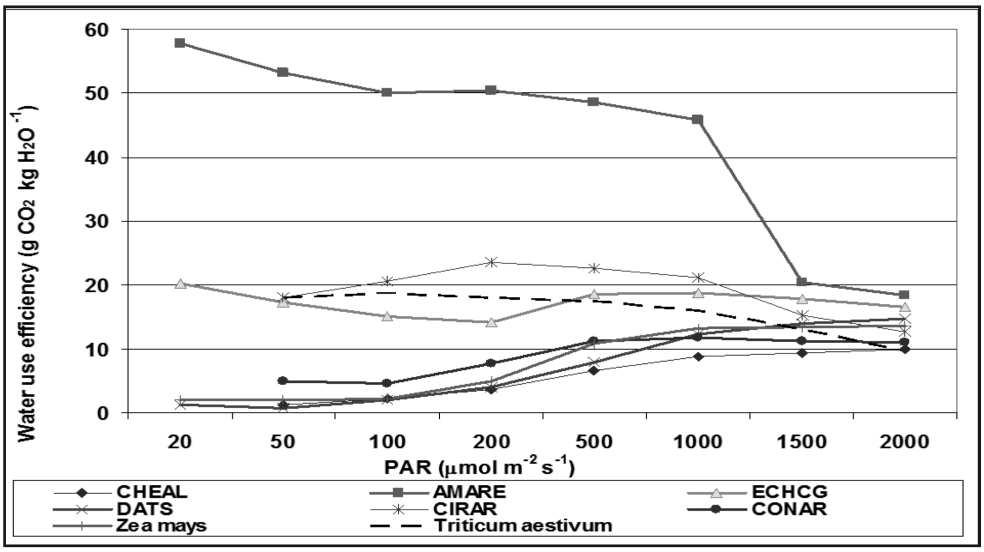
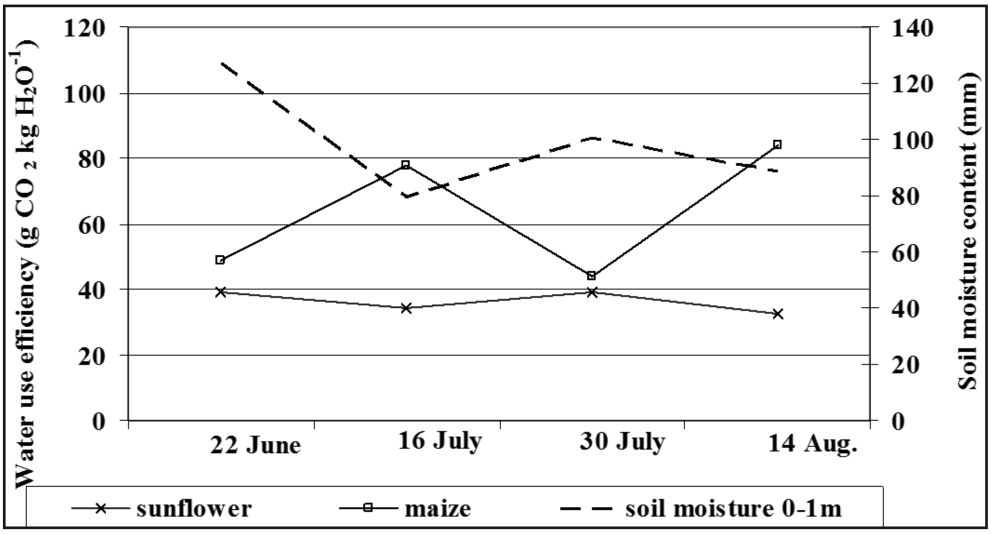


Figure 6 Water use efficiency of maize and sunflower in relation to soil moisture (Debrecen, 2007)



date the higher fertilization levels caused lower water use efficiency. The fertilization has significant effect on the water use efficiency in the monoculture only ($N_0P_0K_0$: 39.52 g CO_2 kg-1 H2O, $N_{120}P_{90}K_{90}$: 44.66 g CO_2 kg^{-1} H_2O). In 2004 we also recorded photosynthesis light curve of some crops and significant weeds. The plants with C4 photosynthesis way can be separated clearly at higher light intensity levels. Figure 5 shows the effect of light intensity on water use efficiency. Increasing light intensity resulted in better water use efficiency of maize. Below the 200 µmol m^{-2} s^{-1} PAR light intensity maize had the lowest net photosynthesis rate beside Datura stramonium and Chenopodium album. Amaranthus retroflexus plants used water much more effectively below 1500 µmol m^{-2} s^{-1} PAR light intensity comparing to other studied weeds or crops.

Table 2 Water use efficiency of maize in different cropyears (Látókép, 2007-2013)

Years	WUE ($g\ CO_2\ kg\ H_2O^{-1}$)	per cent
2010	23.33	100
2011	52.88	227
2012	36.19	155
2013	61.52	264
2007	77.82	334

We analyzed the soil moisture content and the difference of air and leaf temperature in maize and sunflower in 2007. The temperature difference follows the soil moisture change in case of maize, but in sunflower does not. Sunflower could cool its leaves with transpiration in opposite to maize. Sunflower transpirated more water to fix 1 g CO_2 and there was almost no connection between its water use efficiency and soil moisture. In case of maize the higher soil moisture content resulted in lower efficiency of water use, and the low soil moisture resulted in higher efficiency (Figure 6).

The water use efficiency data of maize in the last four years show that the lowest efficiency was in 2010, a year with very good water supply. In droughty years like 2012 and 2013 the efficiency was much better. And the data of very droughty 2007 prove this statement (Table 2).

Conclusions

We found significant, close positive connection between the difference of leaf and air temperature and the water use efficiency of maize. The warmer the leaf comparing to the air, the more the transpirated water to assimilate one unit CO_2. The nutrient supply caused significant difference in the water use efficiency of maize. The lowest efficiency was in the control ($N_0P_0K_0$) plots, the differences were 10-35%. The nutrient supply increased the efficiency of water use of maize. We proved negative connection between the water use efficiency of maize and the soil moisture content in the droughty 2007 year. The higher the moisture content of the soil, the lower the water use efficiency. The increasing light intensity resulted in better water use efficiency of maize up to 1000 µmol photon m^{-2} s^{-1} PAR level. In dry conditions maize uses water very effectively, while the good water supply results in lowering efficiency of water use. Maize transpires 150-300% more water to assimilate 1 g CO_2 in wet years, comparing to dry years or water stress state. The irrigation had significant effect on the water use efficiency of maize, the greatest effect we measured in monoculture.

References

Ben-Asher J., Garcia A. Y Garcia, - Hoogenboom G. (2008): Effect of high temperature on photosynthesis and transpiration of sweet corn (Zea mays L. var. rugosa) Photosynthetica, 46 (4) 595-603.

Csajbók, J.-Kutasy E. (2012): A transzspiráció és a fotoszintetikus aktivitás összefüggései kukoricában Talaj-víz-növény kapcsolatrendszer a növénytermesztési térben (Ed: Lehoczky É.) MTA AK TAKI, Budapest, 151-154.

Hirasawa, T., Hsiao T. C. (1999): Some characteristics of reduced leaf photosynthesis at midday in maize growing in the field. Field Crops Research 62 (1) 53-62.

Janda, T., Szalai, G., Ducruet, J.-M., Páldi, E. (1998): Changes in photosynthesis in inbred maize lines with different degrees of chilling tolerance grown at optimum and suboptimum temperatures. Photosynthetica 35: (2) 205-212.

Kang, S., Shi,W., Zhang, J. (2004): An improved water-use efficiency for maize grown under regulated deficit irrigation. Field Crops Research 67 (3) 207-214.

Kutasy, E., Csajbók, J., (2009): Effects of nitrogen supply on the efficiency of photosynthesis of maize In: C Grignani, M Acutis, L Zavattaro, L Bechini, C Bertora, P Marino Gallina, D Sacco (szerk.) Proceedings of the 16th Nitrogen Workshop: Connecting different scales of nitrogen use in agriculture. 421-422.

Lu, C., Zhang J. (2000): Photosynthetic CO_2 assimilation, chlorophyll fluorescence and photoinhibition as affected by nitrogen deficiency in maize plants. Plant Science.151 (2) 135-143.

Raschke, K. (1970): Stomatal responses to pressure changes and interruptions in the water supply of detached leaves of Zea mays L. Plant Physiology, 45: 415-423.

Shangguan, Z. P., Shao, M. A., Dyckmans, J. (2000): Nitrogen nutrition and water stress effects on leaf photosynthetyc gas exchange and water use efficiency in winter wheat. Environmental and Experimental Botany. 44: 141-149.

Szász, G. (1997): A víz a légkörben, a talajban és a növényben. Meteorológia mezőgazdáknak, kertészeknek, erdészeknek. Eds: Szász G.-Tőkei L. Mezőgazda Kiadó, Budapest 111-172.