Annals of the Academy of Romanian Scientists
Series on Agriculture, Silviculture and Veterinary Medicine Sciences
ISSN 2069 – 1149 Volume 6, Number 1/2017

WATER USE EFFICIENCY OF MAIZE IN FIELD EXPERIMENTS

József CSAJBÓK[1], Erika KUTASY[2],

Abstract. *There is little direct in field information about the effects of the abiotic stress factors such as low soil water content on the photosynthesis system of crops. Some recent publications pay attention on this field of research. The 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 the 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 under dry conditions. In well water supply state maize uses up to 330 per cent more water for 1 g CO_2 assimilation.*

Keywords: maize, water use efficiency, abiotic stress

1. Introduction

We can find some articles according to the topic photosynthesis system and the water use efficiency of maize published in the last decades [1, 2, 3, 4, 5]. 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 [6]. 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 [7].

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 [8]. 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) [9].

[1]Title: PhD, University of Debrecen, Hungary, Faculty of Agricultural and Food Sciences and Environmental Management (e-mail: csj@agr.unideb.hu)
[2] PhD, University of Debrecen, Hungary, Faculty of Agricultural and Food Sciences and Environmental Management (e-mail: kutasy@agr.unideb.hu)

2. Materials and methods

The measurements were carried out between 1999 and 2016 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 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 mm is readily available. The watertable is at 6-8 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 system. 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 IBM SPSS 22.0 statistical software package. The accuracy of the statistical analysis was 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.

3. Results and discussion

To present the water supply state of maize in the studied years we calculated the potential (PET) and actual evapotranspiration (AET) [10] and their ratio. The higher the ratio, the better the water state of the crop, in this case the maize. 2000, 2002, 2007, 2009, 2012 were very dry years, the PET:AET ratio was very low in these growing seasons (Fig. 1, Fig. 2). On the contrary the water supply in 2004, 2005, 2008 and 2010 was very good to maize (Fig. 3).

According to the growing season's PET:AET ratio we can say the years 1999, 2001, 2006, 2011, 2013, 2014, 2016 were average, but in details there are great differences in the distribution of the rainfall. For example 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, while in 2016 after a relatively dry spring season the water supply was good to maize These deviations also resulted in differences in yield (Fig. 4, Fig. 5).

We also can see on the figures that in years with high rainfall the potential evapotranspiration is lower caused by the lower temperature and higher air humidity. Maize prefer warm weather, so farmers usually do not harvest very high yields in these years, despite the good water supply of the crop.

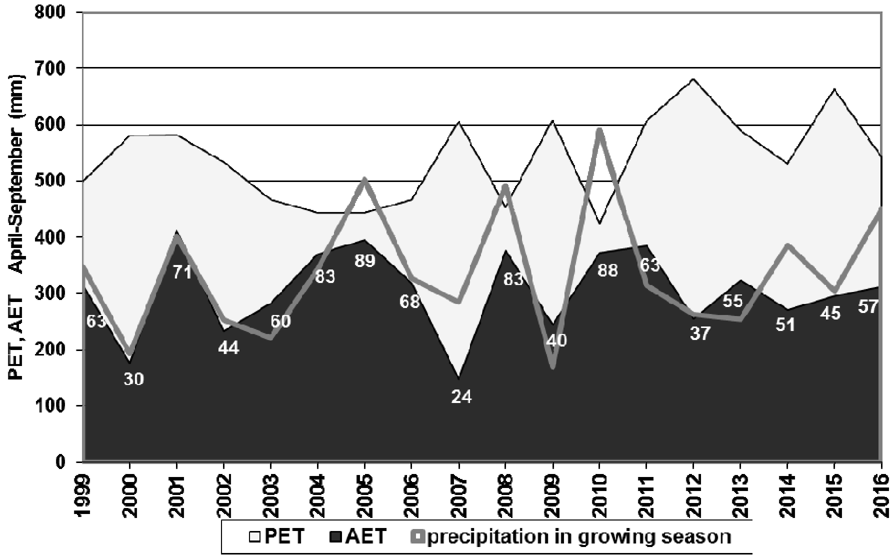

Fig. 1. Estimated PET and AET values, PET:AET ratio and the precipitation in maize growing season (Látókép, 1999-2016)

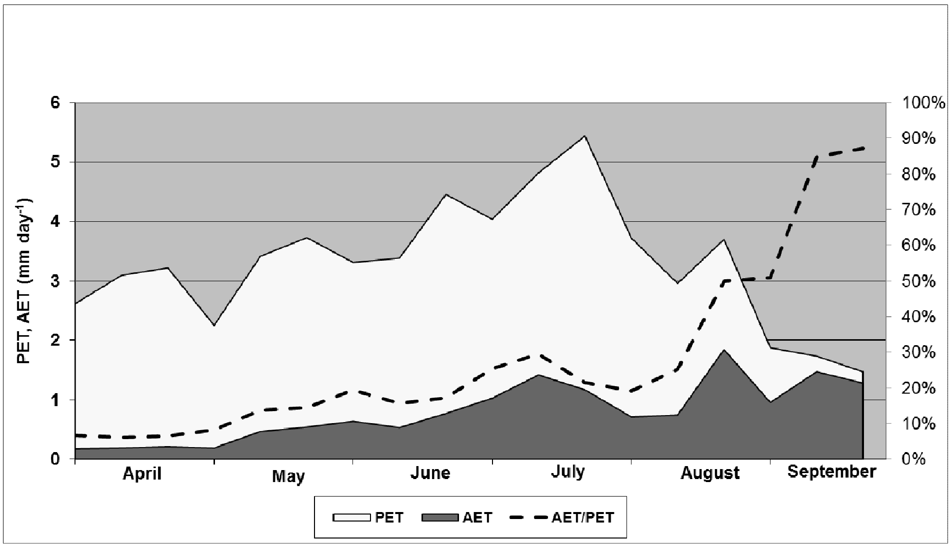

Fig. 2. Estimated PET, AET values and AET/PET ratio in maize growing season (Látókép, 2007)

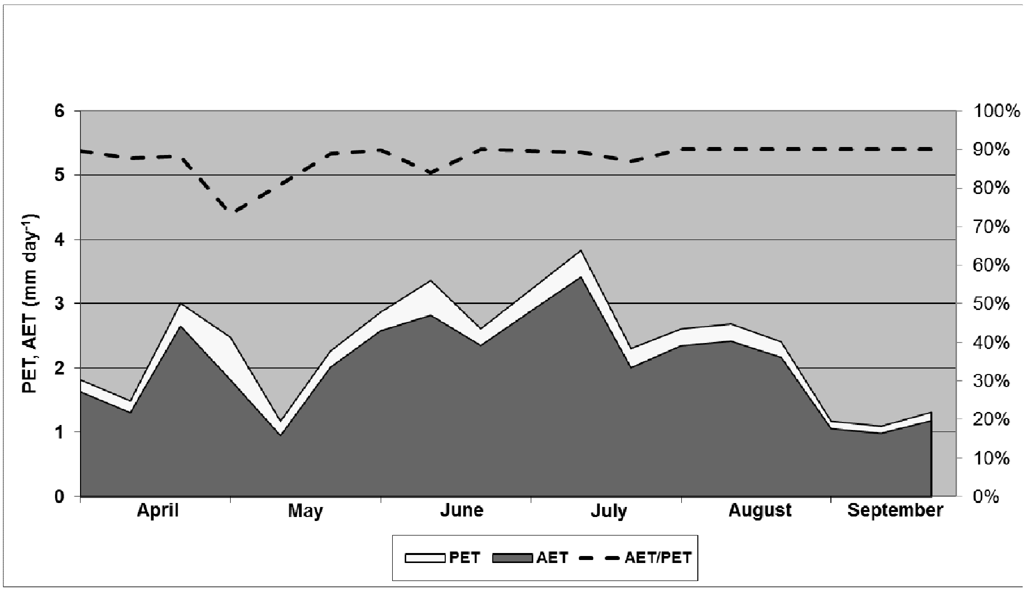

Fig. 3. Estimated PET, AET values and AET/PET ratio in maize growing season (Látókép, 2010)

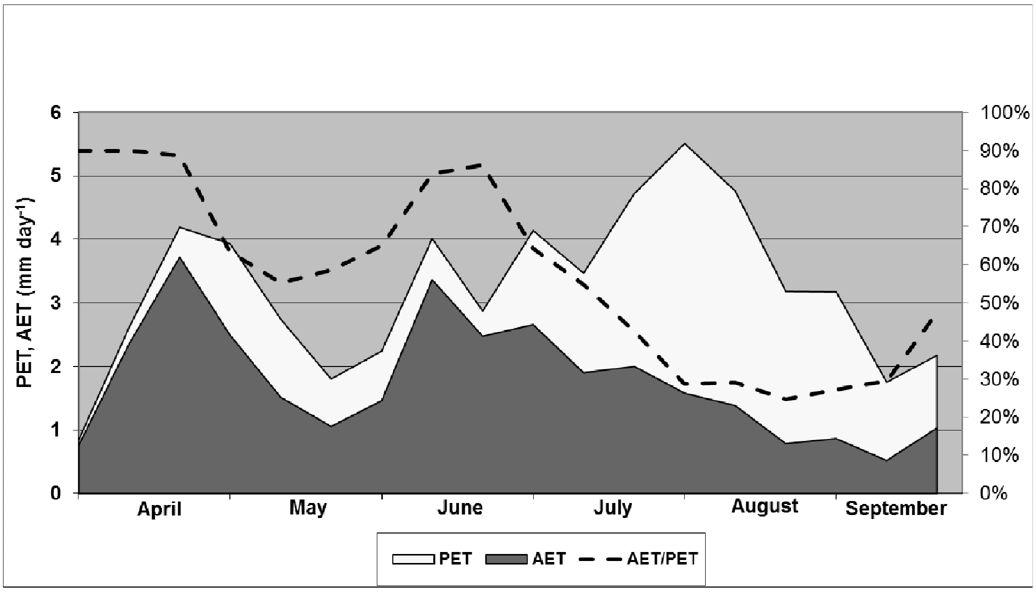

Fig. 4. Estimated PET, AET values and AET/PET ratio in maize growing season (Látókép, 2013)

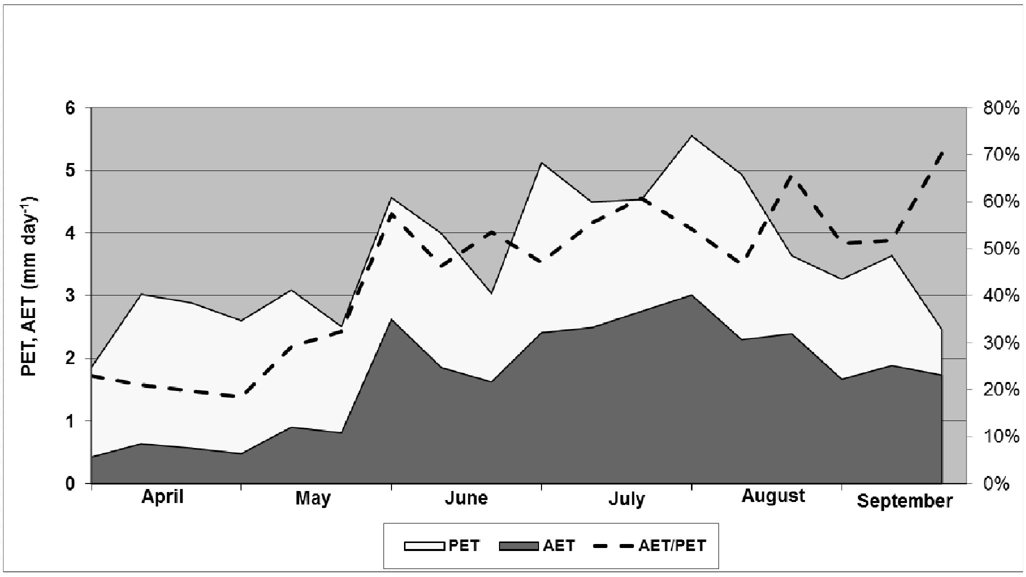

Fig. 5. Estimated PET, AET values and AET/PET ratio in maize growing season (Látókép, 2016)

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.

We calculated the actual water use efficiency (WUE) of the maize using the measured photosynthesis and transpiration data. 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 (LSD5%=1.09). As monoculture means unfavourable water supply comparing to the biculture, this data 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 water stress state.

The irrigation had significant effect on the water use efficiency of maize in the experiment. The greatest effect we measured in monoculture (nonirrigated: 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 (nonirrigated: 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 (nonirrigated: 34.39 g CO_2 kg^{-1} H_2O, irrigated: 35.62 g CO_2 kg^{-1} H_2O).

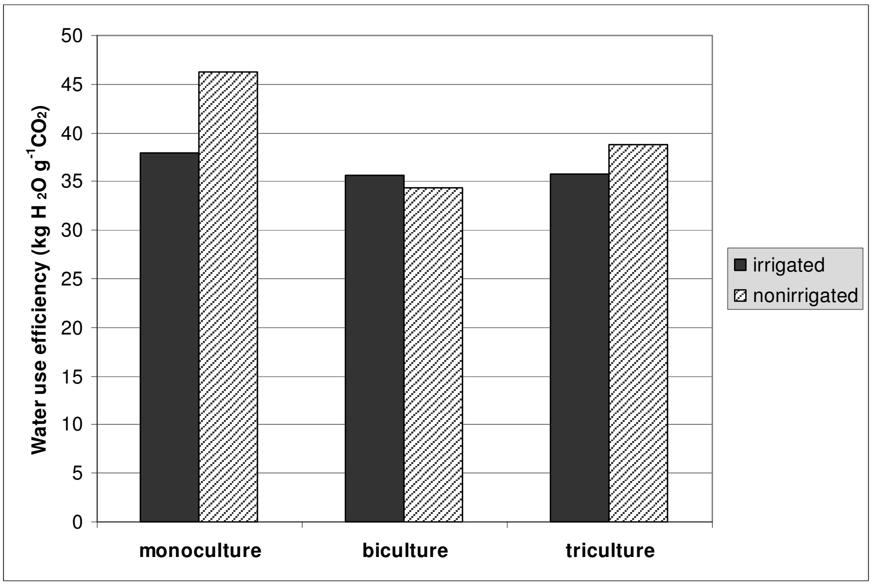

Fig. 6. Water use efficiency of maize in different crop rotation variations (Látókép, 2013)

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

Years	WUE ($g\ CO_2\ kg\ H_2O^{-1}$)	per cent (the basis is 2010)
2007	77.82	334
2009	49.04	210
2010	23.33	100
2011	52.88	227
2012	36.19	155
2013	61.52	264

The water use efficiency data of maize show that the lowest efficiency was in 2010, a year with very good water supply. In droughty years like 2009, 2012 and 2013 the efficiency was much better. And the data of very droughty 2007 prove this statement (Table 2). In wet years maize transpirates 150-330% more water to one gram CO_2 assimilation than in dry years or in water stress (Fig. 6).

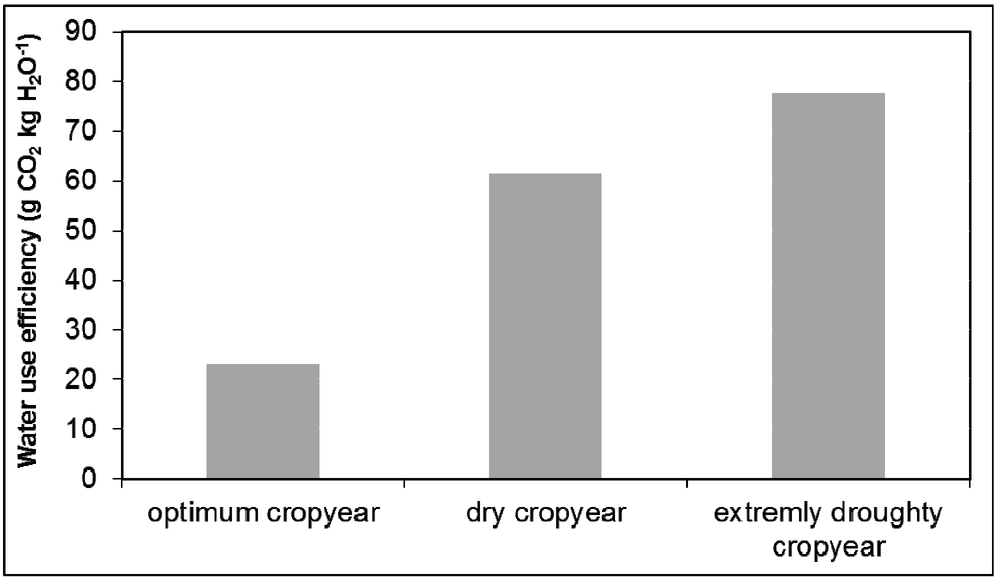

Fig. 7. Water use efficiency of maize in different type cropyears

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.

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.

In dry conditions maize uses water very effectively, while the good water supply results in lowering efficiency of water use. In better water state maize transpirates 150-300% more water to assimilate 1 g CO_2 in wet years, comparing to dry years or water stress state (Fig. 7).

The irrigation had significant effect on the water use efficiency of maize, the greatest effect we measured in monoculture.

R E F E R E N C E S

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

[2] Lu, C., Zhang J. *Photosynthetic CO2 assimilation, chlorophyll fluorescence and photoinhibition as affected by nitrogen deficiency in maize plants*. Plant Science 151 (2) 135 (2000)

[3] Hirasawa, T., HSIAO T. C.: *Some characteristics of reduced leaf photosynthesis at midday in maize growing in the field*. Field Crops Research 62 (1) 53

[4] Csajbók, J.-Kutasy E. *A transzspiráció és a fotoszintetikus aktivitás összefüggései kukoricában Talaj-víz-növény kapcsolatrendszer a növénytermesztési térben (MTA AK TAKI*, Budapest, ISBN: 97896389041-6-4 pp. 151. 2012)

[5] Kutasy, E., Csajbók, J. *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 Proceedings of the 16th Nitrogen Workshop: *Connecting different scales of nitrogen use in agriculture* pp 421-422. (2009)

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

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

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

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

[10] Szász, G. *A víz a légkörben, a talajban és a növényben. Meteorológia mezőgazdáknak, kertészeknek, erdészeknek. szerk. Szász G.-Tőkei L.* (Mezőgazda Kiadó, Budapest p. 111-172, 1997)