Lehr- und Forschungszentrum für Landwirtschaft
Raumberg-Gumpenstein

63. Tagung der Vereinigung der Pflanzenzüchter und Saatgutkaufleute Österreichs 2012, 109 – 112
ISBN: 978-3-902559-88-3

Effect of different soil moisture and meteorological conditions on the water regime of maize (*Zea mays* L.)

Jana Klimešová[1*], Tomáš Středa[1] and Karel Drápal[1]

Abstract

Changes in the water regime of plants in response to different irrigation management were studied in a pot experiment. Stress was induced by drought and its impact was observed on the behaviour of maize. Highly significant correlation coefficients were observed between sap flow and global radiation and air temperatures, respectively. Sap flow was statistically different between irrigation regimes. Effects of global radiation, vapour pressure deficit and water deficit on sap flow were determined. Compared to field conditions soil moisture has a greater effect on sap flow in pot trials (water availability is limited by pot size).

Keywords

Air temperature, biomass, global radiation, sap flow, soil moisture, transpiration

Introduction

Soil water availability, global radiation and vapour pressure deficit are among the main determinants of plant transpiration capacity (ZEPPEL et al. 2008, DU et al. 2011, SHE et al. 2013). Daily or long term characteristics of these indicators affect plant sap flow (NAITHANI et al. 2012). If abiotic stress caused by unavailable soil water occurs - drought stress - it is possible to presume a significant effect of soil moisture on the process of transpiration. Drought stress has been a current issue in many agricultural areas due to uneven rainfall and unusually high temperatures during the growing season. Response to stress depends on its intensity and length of exposure according to the plant genotype. Based on monitoring the sap flow and meteorological values it is possible to characterise water management in plants, detect stress and rate its intensity.

Methods for the detection of sap flow are available that apply heat transmission by water contained in the xylem. These methods include the 'heat pulse method' which monitors gradual flow velocity based on a heat pulse motion in a shortly heated part of the trunk/stem. This method was published by Huber in as early as 1932 (ŠANTRŮČEK 1998). The 'thermal dissipation method' is related to the correlation between the temperature of a heated sensor and flow density (GRANIER 1985). The 'stem heat balance method' (SHB) (KUČERA et al. 1977, ISHIDA et al. 1991, LINDROTH et al. 1995) and the 'trunk sector heat balance method' (SMITH and ALLEN 1996) employ direct electrical heating of tissue and inner heat monitoring to measuring. The outcomes completed with meteorological and physiological characteristics can be used to assess individual subjects as well as forest stands and field crops canopies.

The aim of this work was (i) to identify differences in transpiration of maize plants exposed to various conditions of water supply, and (ii) to characterize the dependence of transpiration on environmental factors (air temperature, global solar radiation, soil moisture) and plant traits.

Material and Methods

A pot trial was established under natural conditions with limited rainfall. Based on physical soil analysis four variants of irrigation were run from BBCH 40 (full water holding capacity: 39%; wilting point: 21%): (A) control: 75% available water holding capacity (AWHC); (B) mild stress: 50% AWHC; (C) medium stress: 25%; and (D): significant stress: 15% AWHC (23% soil moisture). In each pot (269 dm3) 6 maize plants were sown (breeding line 2087, provided by CEZEA Čejč). Phenological data were monitored continuously and in a later phase of the trial also changes of conformation as a result of stress.

Transpiration was monitored by means of a continuous measuring of sap flow. The EMS 62 system (EMS, Brno) uses the SHB method (KUČERA et al. 1977) (*Figure 1*). The SHB is a non-destructive sensitive method based on physical characteristics of water. Sap flow (Q, $kg \cdot h^{-1}$) was measured on two plants per pot from heading (BBCH 50) to full maturity (BBCH 89). Moreover the following meteorological variables were monitored: (i) relative air humidity (%) and air temperature (°C) in 10 min intervals by HOBO RH Temp sensors (Onset Computer Co.), (ii) volumetric soil moisture (%) by automatic electromagnetic sensors VIRRIB (AMET, Velké Bílovice) 15 min intervals, (iii) soil temperature (°C) by resistor sensors Pt100 in 15 min intervals, (iv) global solar radiation ($W \cdot m^{-2}$) measured by LI-COR sensors (LI-COR) in 15 min intervals, and (v) soil water potential (-bar) detected in 15 min intervals by a gypsum block connected to a MicroLog SP datalogger (EMS, Brno).

The measuring period was divided into three periods according to changes in transpiration and plant phenology (1: 27 July to 6 August; 2: 7 to 24 August; 3: 25 August to 14 September). Dependency of transpiration on natural factors (global radiation, air temperature) was assessed for each period separately so that variability of monitored features was closely recorded.

[1] Department of Crop Science, Breeding and Plant Medicine, Faculty of Agronomy, Mendel University, Zemědělská 1/1665, CZ-613 00 BRNO
[*] Corresponding author: Jana KLIMEŠOVÁ, jana.klimesova@mendelu.cz

Data were processed by MINI32 software (EMS, Brno) and statistically analysed, i.e. correlation analysis, analysis of variance including mean comparison by Tukey's HSD test, using STATISTICA 10 (StatSoft Inc., Tulsa, OK).

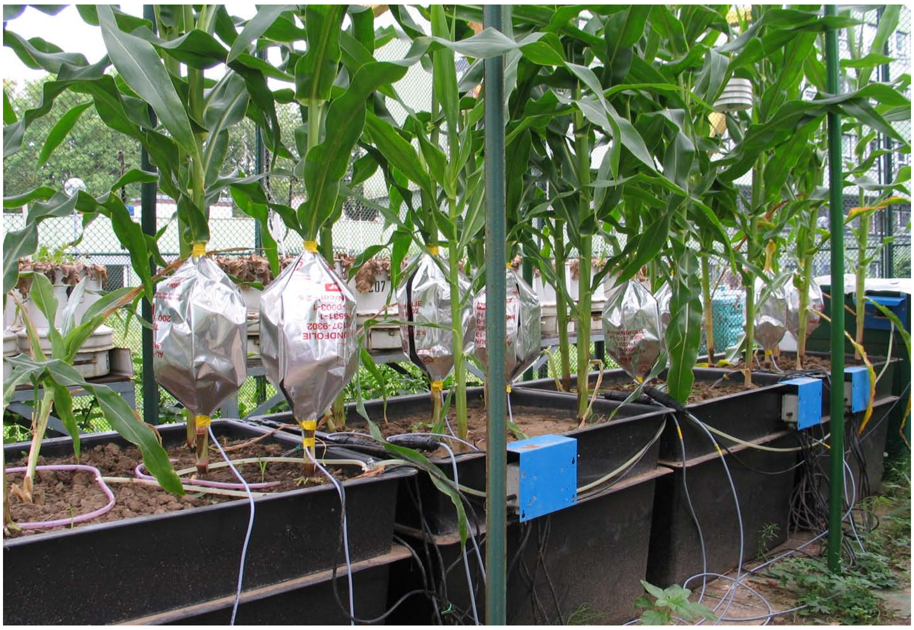

Figure 1: **Sap flow measurements of maize by EMS 62 sensors**

Results

Table 1 shows the strongest relationship between transpiration and air temperature and/or radiation for all irrigation treatments in period 1. During the growing season this dependency decreases most in the stressed variants. In period 3 an increase of dependency on radiation and temperature is evident in the variants of more water supply. A significant positive relation between radiation and sap flow was also observed in cassava (OGUNTUDE 2005), maize (LI et al. 2011) and soybean (GERDES et al. 1994). In trees of *Populus hopeiensis*, *P. simonii* and *Armeniaca ansu* the strongest relation was detected between sap flow and photosynthetically active radiation, at the same time a relation between sap flow and air temperature and air humidity was proved (ZHOU et al. 2008).

Dependency of sap flow on meteorological parameters decreases with increasing water stress. Non-significant correlation for variant D in period 3 are caused by a finished growing season.

Soil moisture varied only minimally in individual variants. Correlation coefficients were determined for average diurnal values of sap flow and soil moisture from the total growing season. A statistically highly significant dependence was discovered in variants C (r=0. 395**) and D (r=0.528**).

The effect of air temperature and humidity on transpiration was also demonstrated for sagebrush (*Artemisia tridentata* var. *vaseyana*) in US semi-desert conditions (NAITHANI et al. 2012). However, these plants only showed weak dependence of transpiration on radiation values. This discrepancy with our results may be explained by different conditions in semi-desert environments where plants are not limited by lack of solar radiation. A greater share of radiation, temperature and air humidity on transpiration values in maize was shown by IRMAK and MUTIIBWA (2010). Only a lesser part of variability was explained by soil moisture. A close correlation of radiation and vapour pressure deficit versus soil moisture and type of plant was proved by sap flow measurement in *Quercus liaotungensis* and *Robinia pseudoacacia* (DU et al. 2011). A significant dependence of sap flow on soil moisture in a *Caragana korshinskii* was observed by SHE et al. (2013).

Plant sap flow capacity reached as much as 45 g of water per hour during the day. Similar maize sap flow values were observed in a pot trial by GAVLOSKI et al. (1991) and in a field trial by BETHENOD et al. (2000). KJELGAARD et al. (1997) determined an average maize transpiration value between 41 and 44 $g \cdot h^{-1}$.

Significant differences among irrigation treatments were observed for diurnal sap flow (*Table 2*). In period 1, i.e. flowering stage, a significant difference was identified among variants A and C, D. In period 2 plant transpiration in the control variant was significantly different from the stressed variants. In period 3 a significant difference was observed between variant D and the other irrigation treatments. Even though transpiration is much dependent on the weather, a different moisture schedule caused significant differences of transpiration in individual variants. Significant differences of sap flow in grapevine of irrigated and water stressed variants were identified by ESCALONA et al. (2002). GAVLOSKI et al. (1991) observed increasing differences of sap flow between control and drought treatments of increasing water stress.

In period 1 similar sap flow was observed for variants A and B plants which decreased with time as suboptimal conditions

Table 1: **Corrleation of sap flow to temperature (TEMP) and global radiation (RAD) with respect to the different irrigation treatments (**, $P \leq 0.01$; * $P \leq 0.05$)**

	Period 1		Period 2		Period 3	
Irrigation	TEMP	RAD	TEMP	RAD	TEMP	RAD
A	0.934**	0.881**	0.627**	0.670**	0.665**	0.640**
B	0.862**	0.873**	0.537*	0.500*	0.674**	0.722**
C	0.902**	0.699*	0.516*	0.604**	0.681**	0.773**
D	0.698*	0.439	0.030	0.563*	0.022	0.101

Table 2: **Average diurnal values of sap flow (kg·h^{-1}) per plant** (Statistically different means according to Tukey's HSD test are indicated by different letters)

Irrigation	Period 1	Period 2	Period 3
A	0.01861 a	0.01044 a	0.00319 a
B	0.01290 ab	0.00668 b	0.00287 a
C	0.00701 b	0.00510 b	0.00341 a
D	0.00698 b	0.00404 b	0.00003 b

continued. In period 3 plants in variant D terminated growth due to persistent water deficit stress. DU et al. (2011) also indicated an effect of plant type and phenology on sap flow capacity. PIVEC et al. (2009) confirmed an effect of maturity and senescence on sap flow of winter rapeseed.

Sap flow measurements by SHB method has detected differences in water management in plants. Plant transpiration in period 2 affected significantly plant height (r=0.973**). A significant effect of transpiration on maize plants height in dependence of soil moisture was also confirmed by GAVLOSKI et al. (1991). Differences in aboveground dry matter biomass were not significant. Leaf area index (LAI) reached similar values in all variants, ranging from 2.6 to 3.3. Generative organs were affected by water deficit more severely.

In period 3 dry matter accumulation was mostly impacted by transpiration. Correlation between sap flow and whole plant dry matter weight was r=0.997**. Sap flow capacity also affected the weight of cobs (r=0.987**). Most plants in variant D produced small or no cobs; a statistically significant difference was found between variant D and the other irrigation treatments. The influence of irrigation treatments on selected plant traits are shown in *Figure 2*.

Although plants in the control variant A (75% AWHC) were not subjected to moisture stress, they produced less then 2% higher dry matter yield compared to variant B (50% AWHC). Compared to variant C (25% AWHC) the yield was even 3% lower. Plants in variant D (15% AWHC) produced 20% lower yield. Water stress did not affect biomass production as much as was presumed according to the decrease of sap flow.

The gained results enable us to identify meteorological parameters which affect transpiration directly and thus simulate the transpiration procedure in a given variety of maize. A function expressing the relation between global radiation, air temperature and sap flow was calculated for individual phenological stages. The function was derived for sap flow in non-stressed conditions.

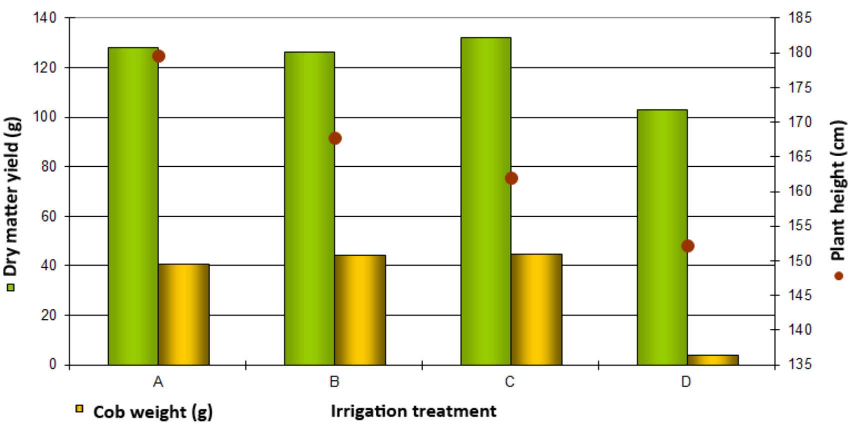

Figure 2: **Selected plant traits according to irrigation regimes**

Sap flow as per average diurnal radiation level (y) and average diurnal air temperature (x) for period 1 is described by the equation

$$z = (a+b\cdot x+c\cdot y)/(1+d\cdot x+f\cdot y)$$

where a= -1.07·10^{-3}, b= 8.24·10^{-6}, c= 1.92·10^{-5}, d= -2.79·10^{-2} and f= 5.14·10^{-5} (R^2=0.977) (*Figure 3A*).

Sap flow as per average diurnal radiation level (y) and average diurnal air temperature (x) for period 2 is described by the equation

$$z = (a+b\cdot\ln(x)+c\cdot\ln(y))/(1+d\cdot x+f\cdot y)$$

where a= -4.03·10^{-3}, b= -9.21·10^{-4}, c= 1.65·10^{-3}, d= -2.40·10^{-2} and f= -6.06·10^{-4} (R^2 = 0.919) (*Figure 3B*).

Sap flow as per average diurnal radiation level (y) and average diurnal air temperature (x) for period 3 is described by the equation

$$z = a\cdot 10^{(b/x+c\cdot y)}$$

where a= 8.29·10^{-1}, b= -1.82·10^{2} and c= 1.08·10^{-2} (R^2=0.823) (*Figure 3C*).

Conclusions

Measurements of sap flow is one way to quantify utilization/flow of water in plants in depending on environmental factors. The 'stem heat balance' method was selected as an exact and sensitive method for sap flow detection in maize. The aim was to study the effect of selected agrometeorological variables on sap flow. At the same time the effect of water deficiency stress on sap flow was observed. Highly significant correlations were found between sap flow and global radiation and air temperature, respectively. Significant differences in sap flow were observed between irrigation regimes. Sap flow was shown to be affected by global radiation, vapour pressure deficit and water deficit. Compared to field conditions soil moisture had a greater effect on sap flow in pot trials (water availability is limited by pot size). Sap flow impacted significantly dry matter yield, cob weight and plant height of monitored plants. A significant effect of soil moisture on dry matter yield or LAI was not detected.

It is possible to anticipate further consequences of water deficit stress - effect on root system parameters and defence mechanism induction on molecular level. These mechanisms will be studied in further experiments.

Acknowledgement

This work was supported by projects of the Internal Grant Agency of Mendel University in Brno (TP 10/2012) and the Ministry of Agriculture (QJ1230056,

The impact of the expected climate changes on soils of the Czech Republic and the evaluation of their productive functions).

References

BETHENOD O, KATERJI N, GOUJET R, BERTOLINI JM, RANA G, 2000: Determination and validation of corn crop transpiration by sap flow measurement under field conditions. Theor Appl Climatol 67, 153-160.

DU S, WANG YL, KUME T, ZHANG JG, OTSUKI K, YAMANAKA N, LIU GB, 2011: Sapflow characteristics and climatic responses in three forest species in the semiarid Loess Plateau region of China. Agric For Meteorol 151, 1-10.

ESCALONA J, FLEXAS J, MEDRANO H, 2002: Drought effects on water flow, photosynthesis and growth of potted grapevines. Vitis 41, 57-62.

GAVLOSKI JE, WHITFIELD GH, ELLIS CR, 1992: Effect of restricted watering on sap flow and growth in corn (*Zea mays* L.). Can J Plant Sci 72, 361-368.

GERDES G, ALLISON BE, PEREIRA LS, 1994: Overestimation of soybean crop transpiration by sap flow measurements under field conditions in Central Portugal. Irrig Sci 14, 135-139.

GRANIER A, 1985: Une nouvelle methode pour la mesure du flux de seve brute dans le trons des arbres. Ann Sci For 22, 193-200.

IRMAK S, MUTIIBWA D, 2010: On the dynamics of canopy resistance: Generalized linear estimation and relationships with primary micrometeorological variables. Water Resour Res 46,

ISHIDA T, CAMPBELL GS, CALISSENDORFF C, 1991: Improved heat balance method for determining sap flow rate. Agric For Meteorol 56, 35-48.

KJELGAARD JF, STOCKLE CO, BLACK RA, CAMPBELL GS, 1997: Measuring sap flow with the heat balance approach using constant and variable heat inputs. Agric For Meteorol 85, 239-250.

KUČERA J, ČERMÁK J, PENKA M, 1977: Improved thermal method of continual recording the transpiration flow rate dynamics. Biol Plant 19, 413-420.

LI H, LIU Y, CAI J, MAO X, 2011: Change of sap flow rate and stem diameter microvariation of summer maize and influenct factors. Trans Chin Soc Agric Eng 27, 187-191.

LINDROTH A, ČERMÁK J, KUČERA J, CIENCIALA E, ECKERSTEN H, 1995: Sap flow by heat balance method applied to small size Salix-trees in a short-rotation forest. Biomass Bioenerg l8, 7-15.

NAITHANI KJ, EWERS BE, PENDALL E, 2012: Sap flux-scaled transpiration and stomatal conductance response to soil and atmospheric drought in a semi-arid sagebrush ecosystem. J Hydrol 464-465, 176-185 (published corrigendum in J Hydrol 476, 496).

OGUNTUNDE PG, 2005: Whole-plant water use and canopy conductance of cassava under limited available soil water and varying evaporative demand. Plant Soil 278, 371-383.

PIVEC J, BRANT V, BEČKA D, 2009: The influence of weather conditions on the sap flow of *Brassica napus* L. during the fructification and maturation stages. Ekológia 28, 43-51.

ŠANTRŮČEK J, 1998: Vodní režim rostlin. In: PROCHÁZKA S, MACHÁČKOVÁ I, KREKULE J, ŠEBÁNEK J (Eds.), Fyziologie rostlin, 52-88. Academia, Praha.

SHE D, XIA Y, SHAO M, PENG S., YU S, 2013: Transpiration and canopy conductance of *Caragana korshinskii* trees in response to soil moisture in sand land of China. Agrofor Syst, in press. DOI 10.1007/s10457-012-9587-4

SMITH DM, ALLEN SJ, 1996: Measurement of sap flow in plant stems. J Exp Bot 47, 1833-1844.

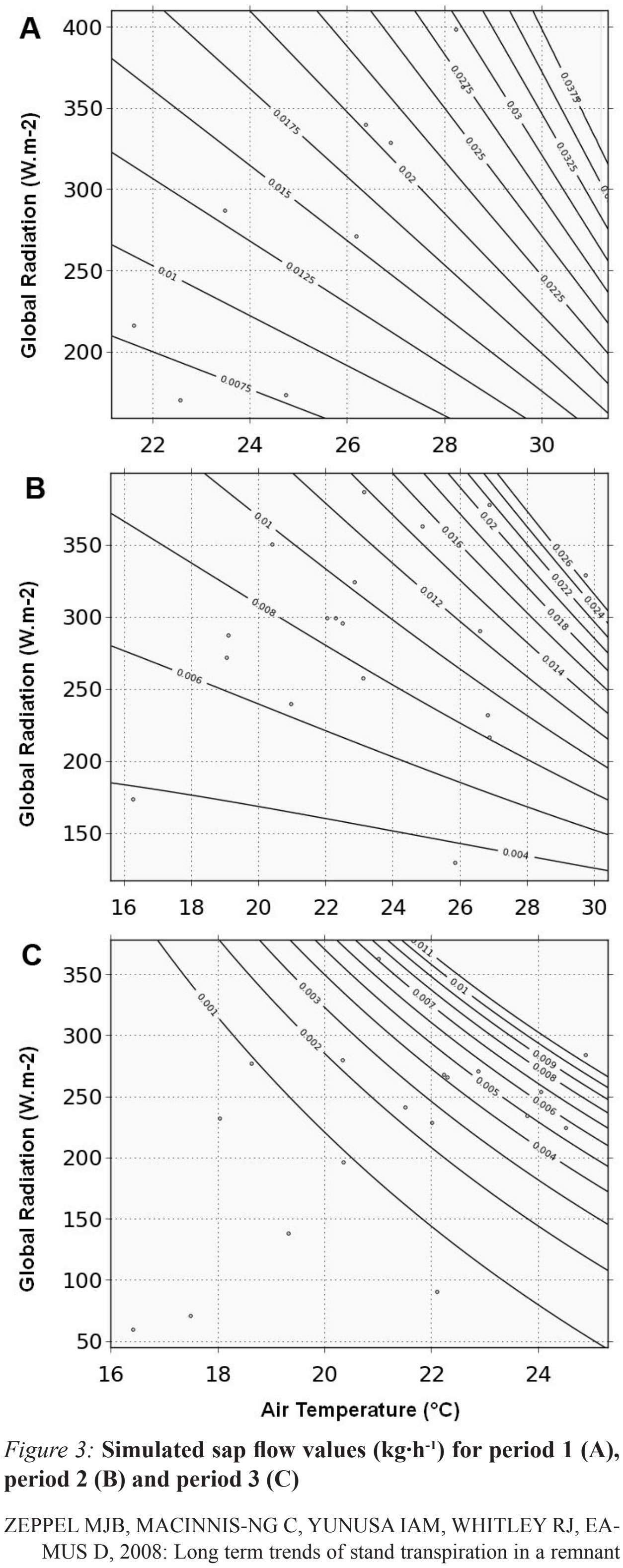

Figure 3: **Simulated sap flow values ($kg \cdot h^{-1}$) for period 1 (A), period 2 (B) and period 3 (C)**

ZEPPEL MJB, MACINNIS-NG C, YUNUSA IAM, WHITLEY RJ, EAMUS D, 2008: Long term trends of stand transpiration in a remnant forest during wet and dry years. J Hydrol 349, 200-213.

ZHOU HG, LIU GQ, JIAO X, WANG HZ, 2008: Water consumption by transpiration of several trees species in the Loess Plateau with mixed water and wind erosion. Acta Ecol Sin 28, 4568-4574.

Note: *The online version of the proceedings includes figures in colour. It can be either downloaded from the homepage of the meeting (http://www.raumberg-gumpenstein.at/ - Downloads - Fachveranstaltungen/Tagungen - Saatzüchtertagung - Saatzüchtertagung 2012) or requested from the corresponding author.*