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Agrometeorological and biological aspects of maize transpiration

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Abstract

Maize (*Zea mays* L.) water regime was monitored in the pot experiment in four variants of irrigation. The aim of the study was to identify the influence of air temperature, drought, intensity of solar radiation on the plant water regime. Potential evapotranspiration calculated according to Penman-Monteith transpiration equation was compared with actual plant transpiration in individual variants. Transpiration rate (sapflow) was measured by stem heat balance (SHB) method. Statistical significant correlation was found between the sapflow and global radiation, sapflow and air temperature, sapflow and leaf surface temperature, respectively. Statistical significant difference between transpiration of plant growing under different irrigation variants was also confirmed.

Key words: soil moisture, meteorological elements, root system, irrigation, sap flow

Introduction

Globally, agriculture accounts for 80 – 90% of the fresh water used by humans, and in many crop production systems, this water use is unsustainable. An interdisciplinary approach involving agronomical opportunities and plant breeding to deliver "more crop per drop" is needed (Davies et al., 2011). For wheat, maize and barley, global yields have clearly responded negatively to increasing temperatures. Moisture certainty analyses in the Czech Republic proved an increase of the driest areas and drought event probability increased in the 1961–2010 period (Středová et al., 2011).

In the field, the upper limit of water productivity of well-managed, disease-free, water-limited cereal crops is typically 20 kg ha^{-1} mm^{-1} (grain yield per water used). The present increase in the CO_2 concentration has also increased root water uptake (Qiao et al., 2010). Therefore, it is surprising that breeding (for example) wheat for drought tolerance has resulted in small root/shoot ratios (Ma et al., 2010).

Effective use of water (EUW) implies maximal soil moisture capture for transpiration, which also involves reduced non-stomatal transpiration and minimal water loss by soil evapotranspiration. Breeding for maximal soil moisture capture for transpiration is therefore the most important target for yield improvement under drought stress (Blum, 2009). Středa et al. (2012) conclude that differences in the EUW expressed as different yields under the same conditions can be partly attributed to different root system sizes (probably due to deeper rooting) and can be improved by breeding.

Based on monitoring the sap flow and meteorological values it is possible to characterize 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. The outcomes completed with meteorological and physiological characteristics can be used to assess individual subjects as well as forest stands and field crops canopies (Středa, 2013).

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

Materials and methods

A pot trial was established under natural conditions with limited rainfall. Based on physical soil analysis (full water holding capacity: 39 volume percent; permanent wilting point: 21 volume percent), four variants of irrigation. Sap flow measurement was started at the stem elongation in phenological growth stage BBCH 39 (the BBCH – scale is a system for a uniform coding of phenologically similar growth stages of plant species; Meier, 1997): (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 (200 dm^3), 6 maize plants were sown (breeding line 2087, provided by CEZEA Čejč). Phenological data were monitored continuously and in the later phase of the trial, changes of conformation as a result of stress were studied, too. Transpiration was monitored by means of a continuous measuring of sap flow in 10-minute interval. The EMS 62 system (EMS, Brno) uses the SHB method (Kučera et al., 1977) was used. Sap flow (Q, $kg.h^{-1}$) was measured on two plants per pot from heading (BBCH 50) to full maturity (BBCH 89). Moreover, the following meteorological variables were monitored:

1. relative air humidity (%) and air temperature (°C) by HOBO RH Temp sensors (Onset Computer Co.) in 10-minute intervals,
2. volumetric soil moisture (%) by automatic electromagnetic sensors VIRRIB (AMET, Velké Bílovice) in 15-minute intervals,
3. global solar radiation ($W.m^{-2}$) measured by LI-COR sensors (LI-COR) in 15-minute intervals,
4. leaf surface temperature (°C) by infrared thermometer Raytek MX4 Raynger® MX4™ in 1-minute intervals; the sensor measures the surface temperature with resolution of 0.1 °C and accuracy of 1.0 °C,
5. Wind speed in canopy ($m.s^{-1}$) by anemometer W1 (Tlusťák, Praha) in 10-minute intervals.

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

Data of sap flow, i.e. transpiration intensity and meteorological data, were always evaluated only for the light part of a day (from sunrise to sunset).

Results and discussion

Differences in transpiration of maize (*Zea mays* L.) plants in four soil moisture regimes were quantified in a pot experiment. The transpiration was measured by "Stem Heat Balance" method. The dependence of transpiration on air temperature, humidity, global solar radiation, soil moisture, soil water potential and soil temperature was quantified.

Cross correlation of data was calculated and time distance of the transpiration reaction to abiotic factors was established (the example on Fig. 1 and Fig. 2). This phenomenon is proved by the course of transpiration in 24th – 26th July, 2013, when the studied meteorological elements were continually recorded in detailed one-minute steps. The fastest reaction was observed when air humidity and temperature and wind speed (0 – 3 minutes) changed. Increase of the leaf temperature caused increased rate of transpiration in a time period of 5 minutes. 10 minutes after changing the radiation intensity, the plant reacted by altering its transpiration.

Significant relationship between transpiration and global radiation and air temperature (in the 1. vegetation period in no-stress variant, r = 0.881**, r = 0.934**) was found out.

Global radiation has a primary effect on transpiration of plants (Gao et al., 2010), however, in case of drought stress occurrence, one may expect a major influence of soil moisture on the course of transpiration (Novák et al., 2005). A crop’s reaction to the decrease soil water capacity is different for dissimilar crop species. High evapotranspiration requirements of the environment may cause loss of soil water supplies through excessive transpiration in non-sensitive plants (Yang et al., 2012).

The transpiration was significantly influenced by soil moisture (r = 0.395**, r = 0.528**) in moderate and severe drought stress. Conclusive dependence of transpiration on leaf temperature (r = 0.820**) and wind speed (r = 0.710**) was found. Correlation between transpiration and plant dry matter weight (r =

0.997**), plant height (r = 0.973**) and weight of corn cob (r = 0.987**) was found out.

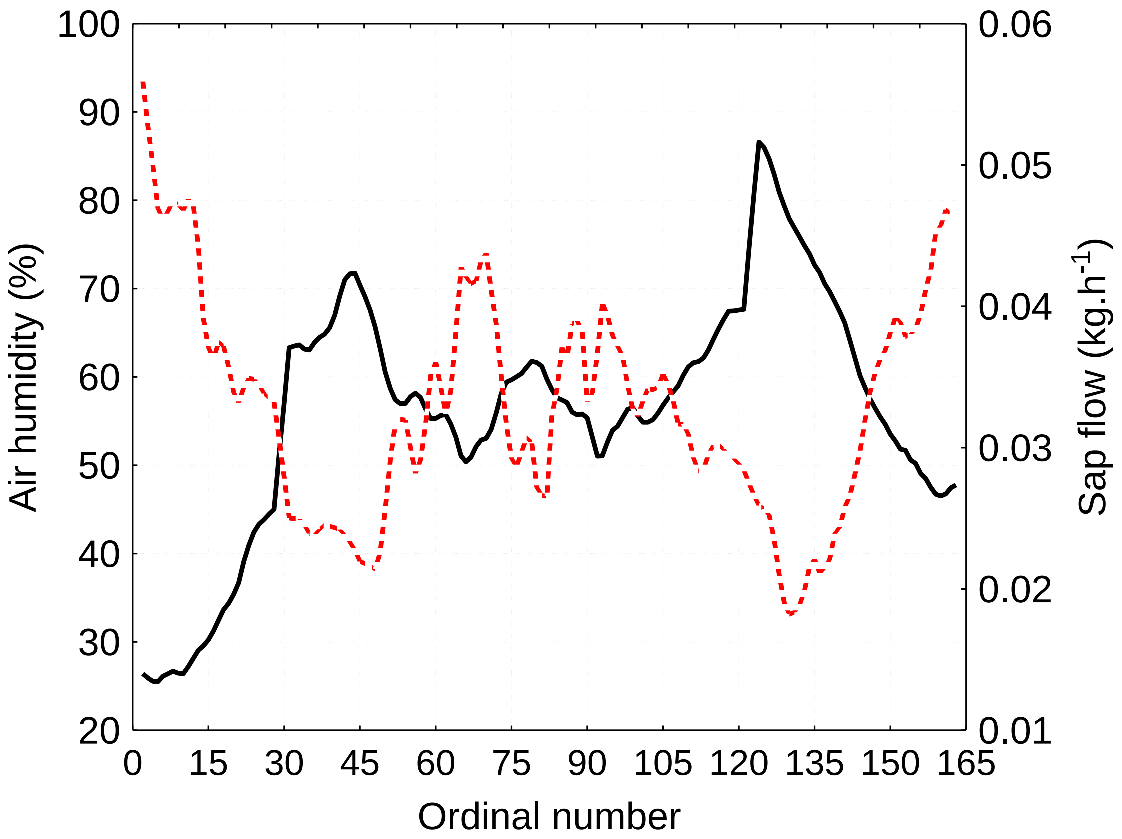

Fig. 1 Course of sap flow (red line; kg.h^{-1}) in dependence on air humidity (black line; %); correlation coefficient of dependence among transpiration and air humidity r = -0.660

Potential evapotranspiration calculated according to Penman-Monteith transpiration equation was compared with actual plant transpiration in individual variants (Fig. 3).

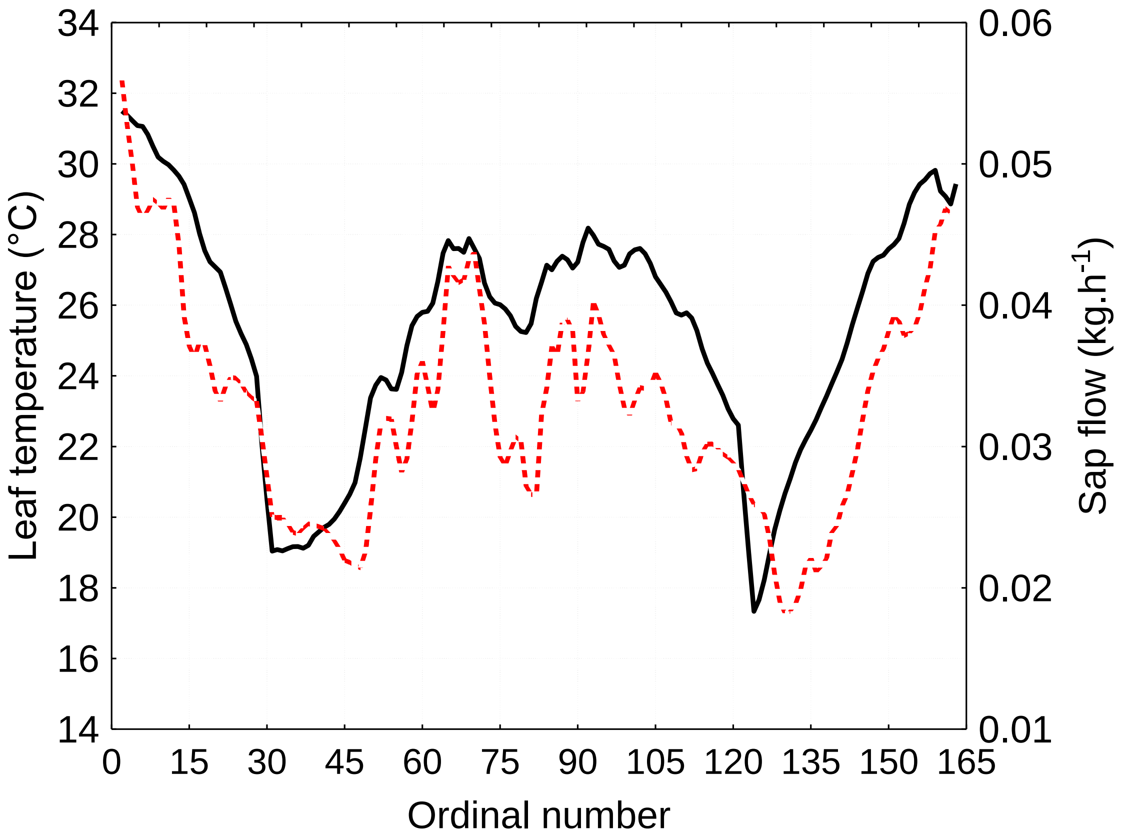

Fig. 2 Course of sap flow (red line; kg.h^{-1}) in dependence on leaf area surface temperature changes (black line; °C), correlation coefficient of dependence among transpiration and leaf surface temperature r = 0.820

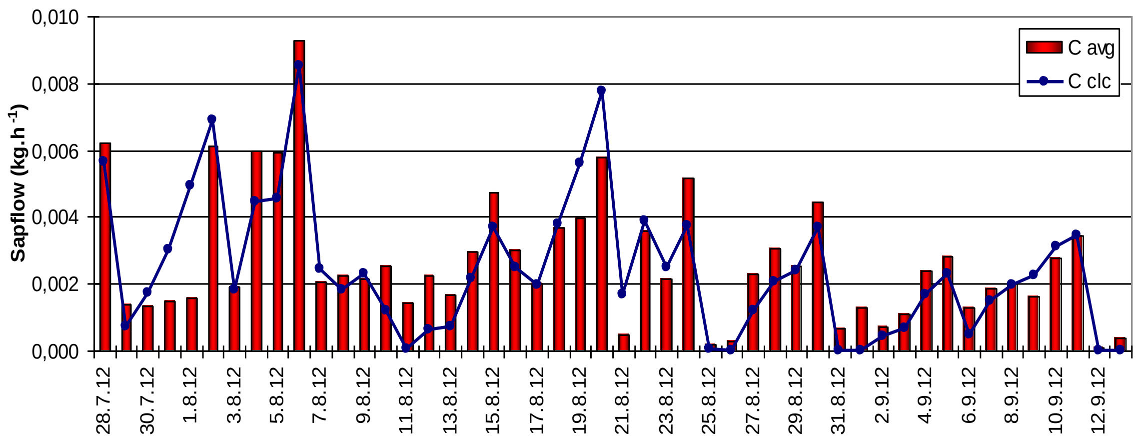

Fig. 3 The course of measured (C avg) and calculated (C clc) transpiration in variant C (soil moisture 25 % of available water holding capacity)

The measuring period was divided into three periods according to changes in transpiration and plant phenology. Dependency of transpiration on natural factors was assessed for each period separately so that variability of monitored features was closely recorded. For example, sap flow as per average diurnal radiation level (y) and average diurnal air temperature (x) for period 1 is described by the equation:

$$z = (a+bx+cy)/(1+dx+fy)$$

where: $a = -1.07 \times 10^{-3}$, $b = 8.24 \times 10^{-6}$, $c = 1.92 \times 10^{-5}$, $d = -2.79 \times 10^{-2}$ and $f = 5.14 \times 10^{-5}$ (R^2=0.977).

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 (leaf area index) 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.

Conclusion

Abiotic stress is a main cause of reduced yield in case of healthy plants. The main current problem is lack of soil water or soil drought and high air temperatures respectively. Stand monitoring of meteorological elements is crucial for precise description of microclimatic conditions in the stand and their influence on plants physiological processes. Outcomes of microclimate monitoring provide valuable data for growth, phytopathological, yield and irrigation models and wide range of other applications.

The results of instrumental measuring of field crops transpiration under diverse moisture conditions at a concurrent monitoring of the meteorological elements spectra are rather unique. These results will be utilized in the effort to make calculations of the evapotranspiration in computing models more accurate.

Highly significant correlation coefficient values were found for sap flow and global radiation performance and for sap flow and air temperature. Simultaneously, statistically significant differences among sap flow values and selected irrigation regimes were quantified. Although sap flow is strongly affected by the global radiation performance and saturation supplement, the effect of water deficiency became evident. In comparison to field conditions, soil moisture in a pot trial had a greater impact on sap flow (water availability is limited by pot size). Nevertheless, the information capacity of this experiment is significant in this case.

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Summary

Měření transpiračního toku (sapflow) je jedním ze způsobů jak kvantifikovat využití/tok vody rostlinami v závislosti na faktorech prostředí. Metoda stem heat balance (SHB) byla zvolena jako přesná, citlivá metoda pro detekci sapflow u kukuřice s cílem zjistit míru ovlivnění transpirace vybranými meteorologickými prvky. Zároveň byl pozorován stres suchem a jeho vliv na průběh transpirace. Na základě rovnice pro výpočet potenciální evapotranspirace Penman-Monteith byla vypočtena potenciální transpirace pro 4 varianty závlahového režimu. Byly nalezeny vysoce průkazné hodnoty korelačního koeficientu pro sapflow a příkon globální radiace resp. sapflow a teplotu vzduchu, sapflow a teplotu povrchu listů, stejně jako pro rychlost proudění vzduchu. Současně byly potvrzeny statisticky vysoce průkazné rozdíly hodnot sapflow mezi všemi variantami. Přestože je transpirace silně ovlivněna výkonem radiace, teplotou vzduchu a sytostním doplňkem, projevil se vliv vodního deficitu. V závěru vegetace byla transpirace ovlivněna stárnutím rostlin. Můžeme předpokládat další důsledky stresu suchem na rostlinný metabolismus a jeho projevy na růstu nadzemní části rostlin i kořenového systému. Pro přesnější identifikaci stresových projevů byly hodnoceny fytometrické charakteristiky pokusných rostlin a identifikován nástup stresu i na molekulární úrovni.

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