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STOMATAL RESPONSES OF DROUGHT AND HEAT STRESSED LINDEN (*TILIA* SP.) LEAVES

Márk STEINER*, Endre György TÓTH, Ágota JUHÁSZ, Magdolna Sütöriné DIÓSZEGI, Károly HROTKÓ

Corvinus University of Budapest, Hungary

Leaf gas exchange was investigated on six linden cultivars from *Tilia cordata* Mill., *T. platyphyllos* Scop., *T. tomentosa* Moench and *T. americana* L. After the morning peak rapid stomatal closure was detected on leaves of *T. cordata* 'Savaria', 'Greenspire' and *T. platyphyllos* 'Favorit'. The stomatal conductance on leaves of *T. tomentosa* 'Szeleste' after the midday drop was significant higher, while highest was on *T. americana* 'Redmond' leaves during the whole day. According to the effect of leaf surface temperature on stomatal conductance three groups of the examined linden cultivars were appointed. Corresponding to their drought and heat adaptability the performance of leaves of *T. tomentosa* cultivars showed intermediate level of transpiration. The large cultivar differences in the performance of leaf gas exchange should be considered at evaluation of drought stress adaptability and environmental benefits (CO_2 fixation, O_2 and vapor release) of *Tilia* cultivars.

Keywords: CO_2 assimilation, environmental benefits, transpiration, urban forestry, water use

Introduction

Linden species (*Tilia* sp.) are important in urban forestry of Central Europe (Radoglou et al. 2008) and are widespread planted in form of different cultivars. The following species are commonly planted for urban forestry in Hungary: *T. cordata* Mill. and *T. platyphyllos* Scop. (native to Europe forming climax forest); *T. tomentosa* Moench, (native to Southern Europe and Asia); *T. americana* L. (cultivars were introduced recently). Despite of their importance, there is little and inconsistent knowledge on the drought tolerance and leaf gas exchange performance of linden cultivars under urban conditions.

Most of the authors agree on wider adaptability of *T. cordata* Mill. (Hölscher, 2004; Hölscher et al., 2005; Radoglou et al., 2008), while data of Köcher et al. (2009) indicate moderate drought sensitivity. Results of Fini et al. (2009) indicate that *T. tomentosa* and *T. cordata* are more drought tolerant during establishment than *T. platyphyllos*. Similarly inconsistent data are available on drought tolerance of *T. americana* (Abrams et al., 1998; Klos et al., 2009; Gustafson and Sturtevant, 2012; Gilman and Watson, 2012).

Water stress results in stomatal closure and reduced transpiration rates, decrease in the water potential of plant tissues, and diminish the photosynthesis. Stomatal control of leaf transpiration is considered as short term dynamic adaptation to water stress; the reduced transpiration contributes to avoiding decrease of leaf water potential (Sperry, 2000; Bréda et al., 2006). The above leaf gas exchange characteristics influence the drought adaptability and some major environmental benefits (CO_2 fixation, O_2 and vapor release) of urban trees. Since there are little and inconsistent data on drought adaptability of linden cultivars we aimed in this work to evaluate the leaf gas exchange, stomatal performance of leaves on different linden taxa under drought stress conditions in order to gain information on the diurnal course of stomatal conductance.

Materials and methods

Site conditions

The investigations were carried out in Soroksár Station of Experimental Farm of Corvinus University of Budapest. Soroksár station (47° 38′ LN; 19° 14′ LE, 103 m above the sea level) is located in Central Hungary, South-East of Budapest. The yearly average temperature is 11.3 °C, and the total sunshine is 2079 hours. Average annual rainfall is about 550 mm falling mainly in May and June. The soil type is light sandy, lime content is around 2.5 %, soil organic matter is low (0.8–0.9 %), pH is 7.7.

An automatic weather system was installed close to the investigated trees (~300 m) to measure meteorological variables at 10 minutes interval, recorded by Campbell CR 100 data loggers. Temperature and relative humidity were observed by Vaisala HMP35 in the research station (Fig. 1). 2011 was extremely droughty year in Hungary. The month August is characterized by increasing air temperature and decreasing air humidity. Further on the low amount of rain measured on the investigated

*Correspodence: Márk Steiner, Corvinus University of Budapest, Faculty of Horticultural Science, Department of Floriculture and Dendrology, Hungary, Budapest, 1118. Villányi út 29–43, phone +36-1-4826271, e-mail: mark.steiner@uni-corvinus.hu

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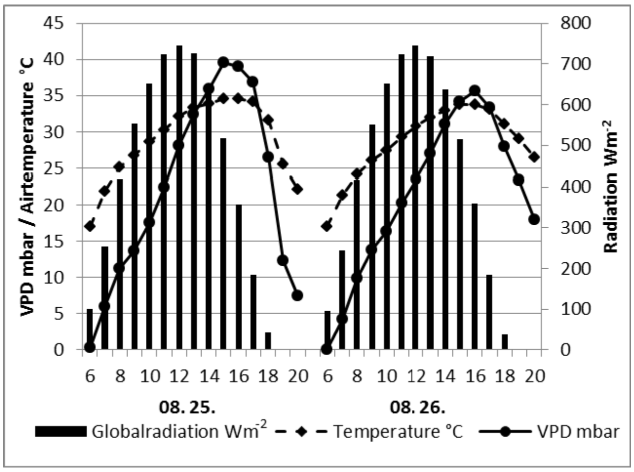

Figure 1 Global radiation, air temperature and vapor pressure deficit (VPD) on the days of investigations in 2011

area (total 2.2 mm precipitation in the whole month of August 2011) increased the drought.

Plant material and methods of leaf gas exchange measurements

Six linden cultivars propagated by budding, were involved in the trial: *Tilia americana* 'Redmond', *Tilia cordata* 'Greenspire', *T. c.* 'Savaria', *Tilia platyphyllos* 'Favorit', *T. tomentosa* 'Szeleste' and *T. t.* 'Zentai Ezüst'. The investigated linden trees were planted in first week of December 2009, with a trunk circumference 120–140 mm.

The parameters of leaf gas exchange were investigated by using portable infrared gas analyzer (LCi, ADC BioScientific Ltd). Healthy and well developed trees were chosen to take the measurements; four trees from each cultivars. We measured the leaf gas exchange on four leaves from each tree, possibly with similar PAR exposition, according to the points of the compass, on each side of trees. The measurements were taken in 2011 august 25 and 26, with very similar meteorological characteristics (Fig. 1). The measurements started at 6:30 AM and finished at 7:30 PM. Measurements of one series (four leaves on one tree of the six cultivars) took one hour and were repeated in two hour intervals from 6:30 AM to 7:30 PM. Data were analyzed with SPSS 2.0, Repeated measures ANOVA and One-way ANOVA were used. Data of species and cultivars were compared to *T. tomentosa* 'Szeleste', which is one of the most widespread planted registered cultivar in Hungary.

Results and discussion

The temperature of measured leaves on different linden cultivars showed in each time intervals significant differences (Fig. 2). There are distinct groups of cultivars, where the leaf temperature showed more or less similar performance. The lowest leaf temperature was measured on *T. americana* cultivars, except for the late afternoon hours (16:00–20:00). In the next group of *Tilia cordata* cultivars there are significant differences within the group in the early hours; between 12:00 – 14:00 all the *T. cordata* cultivars showed similarly mesic leaf temperature. The highest leaf temperature was measured in each time interval on *T. tomentosa* cultivars, while *T. platyphyllos* 'Favorit' showed leaf temperature between *T. cordata* and *T. tomentosa* cultivars.

The daily course of stomatal conductance (gs) showed a performance typical to drought stressed plants (Fig. 3). The daily maximum was achieved between 8:30 to 9:30, followed by rapid decrease to very low level, but with considerably large cultivar differences.

In the early morning (6:30 to 7:30) low stomatal conductance was measured on leaves of *T. platyphyllos* 'Favorit' and on both *T. cordata* cultivars, compared to the control (*T. tomentosa* 'Szeleste'). In the daily maximum period from 8:30 to 9:30 the stomatal conductance of *T. cordata* 'Savaria' was significant lower, while *T. americana* 'Redmond' was higher than that of control. In the following sections of the day until 19:30 the stomatal conductance of *T. americana* 'Redmond' leaves remained

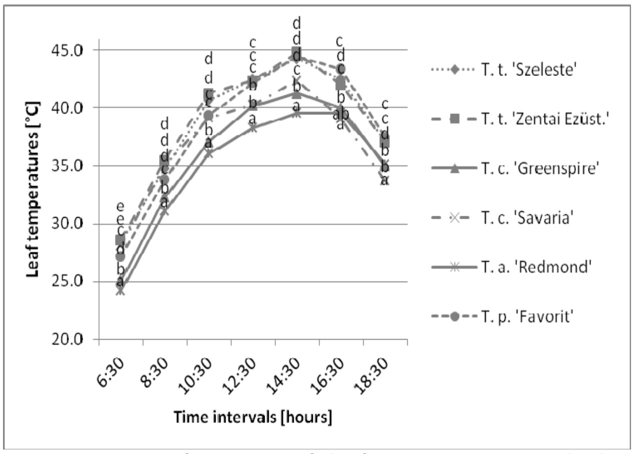

Figure 2 Performance of leaf temperature on linden cultivars

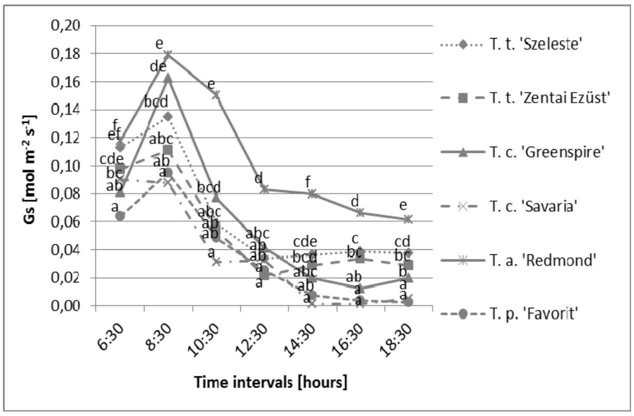

Figure 3 Daily course of stomatal conductance of linden leaves in mol m^{-2} s^{-1}

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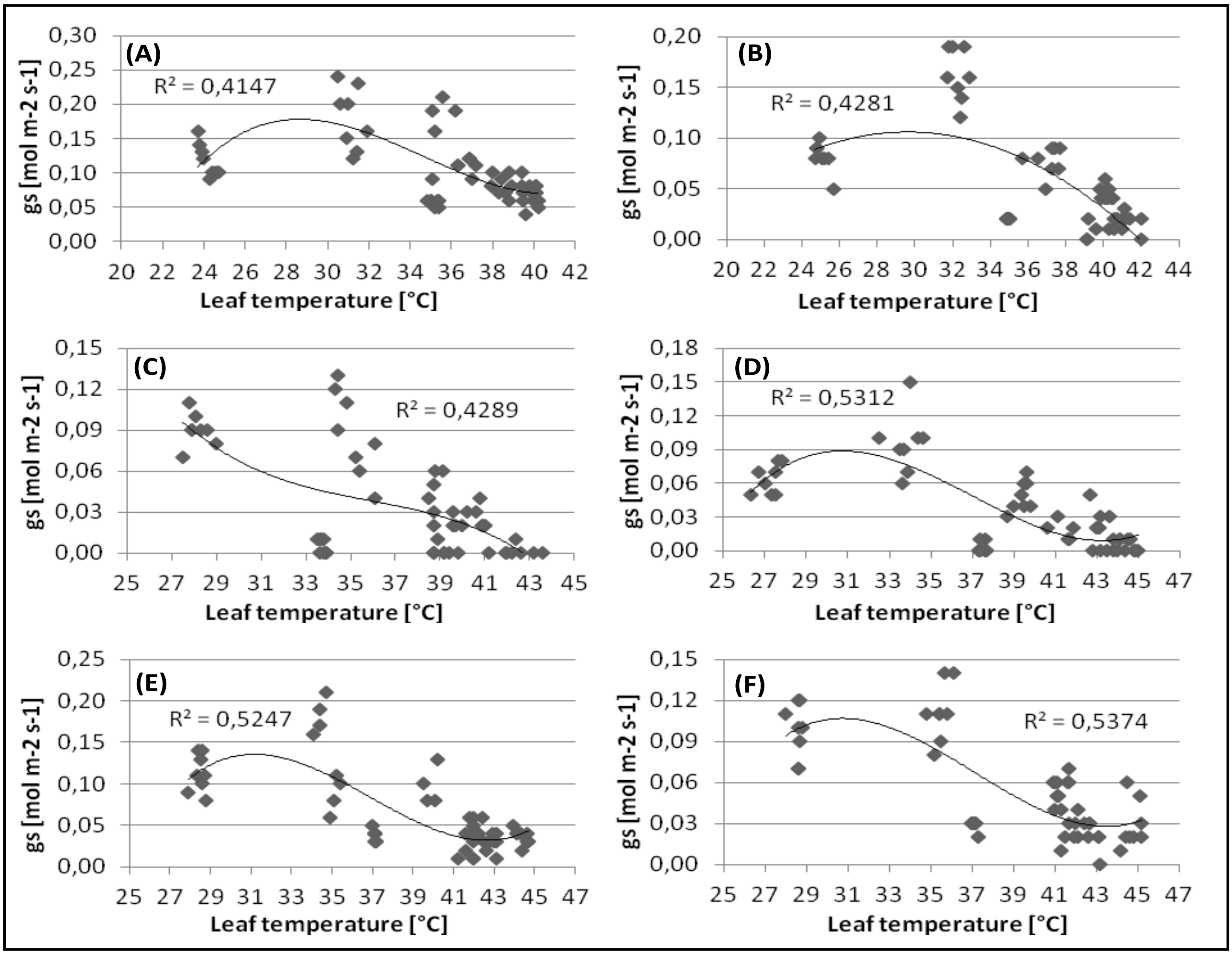

Figure 4 Regression analysis ($n = 56$) of the six *Tilia cultivars* stomatal conductance (gs) by leaf temperature (A – *T. a.* 'Redmond', B – *T. c.* 'Greenspire', C – *T. c.* 'Savaria', D – *T. p.* 'Favorit, E – *T. t.* 'Szeleste', F – *T. t.* 'Zentai Ezüst')

higher than that of control during the whole day. On the other hand, *T. cordata* 'Savaria' and *T. platyphyllos* 'Favorit' showed significant lower stomatal conductance in the afternoon period from 14:30 to 19:30 (Fig. 3). By the end of the day, as the global radiation reduced to minimum, similar differences remained between cultivars.

The six examined linden cultivars may be divided into three different groups under the relationship between leaf surface temperature and stomatal conductance (Fig. 4). The leaf surface temperature of *T. americana* 'Redmond' did not climb over 41 °C, and nor the stomatal conductance declined beneath 0.05 mol m^{-2} s^{-1}. At same time, the temperature of measured leaves on *T. cordata* 'Greenspire', *T. c.* 'Savaria' and *T. platyphyllos* 'Favorit was higher, while their stomatal conductance was close to zero.

The third group is constituted by *T. tomentosa* 'Szeleste' and *T. t.* 'Zentai Ezüst'. Their leaf temperature was the highest (45 °C), however their stomatal conductance remained relative high (0.03 mol m^{-2} s^{-1}).

The leaves showed a diurnal course of stomatal conductance typical to water stressed plants: the daily maximum was around 8:30, than decreased to the minimum. The leaves of *T. cordata* 'Greenspire', 'Savaria' and *T. platyphyllos* 'Favorit' showed low level of stomatal conductance during the whole day. This strategy as a short term dynamic adaptation to water stress may efficiently contribute to the water saving (Sperry et al. 2002; Yordanov et al. 2003; Bréda et al., 2006). The largest conductance was measured during the whole day on *T. americana* 'Redmond', which is in correspondence with its low leaf temperature (Fig. 2 and Fig. 3). Both *T. tomentosa* cultivars produced a second minor peak in the afternoon.

The above observation suggests considerable cultivar differences in adaptability to water stress conditions. Cultivars of *T. cordata* and *T. platyphyllos* showed an efficient short term dynamic adaptation to water stress by stomatal control (Sperry, 2000; Bréda et al., 2006), while cultivars of *T. tomentosa* and *T. americana* could maintain the transpiration of leaves on a relative higher level and produce a second peak after the midday drop. The high stomatal conductance and transpiration of *T. americana* 'Redmond' leaves support the Gilman

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and Watson's (2012) statement on drought tolerance of this cultivar. Maintaining the steady water status of *T. americana* 'Redmond' leaves requires double amount of water supply.

Strong correlation was found between leaf temperature and stomatal conductance (Fig. 4). Although the leaf transpiration alone is not an appropriate indicator of drought tolerance of linden cultivars, the differences between cultivars in leaf gas exchange characteristics suggest need on further investigations. The performance of *T. tomentosa* and *T. americana* indicate that in the soil-plant-air complex of these species there might be a more efficient mechanism in water uptake or larger water reservation and supply capacity, which allows maintaining the higher level of transpiration. The above leaf gas exchange characteristics strongly influence the drought adaptability, ornamental value and the environmental benefits (CO_2 fixation, O_2 and vapor release) of the investigated *Tilia* cultivars under stress conditions.

Acknowledgment

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