Temporal variations of transpiration and latent heat fluxes from isolated linden crowns and lawns in a park at Strasbourg, France

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1. INTRODUCTION

In a context of global climate change, mitigating the “urban heat island” effect is becoming an urging necessity with respect to human health. Among the different mitigating strategies, increasing the vegetated surface areas, such as trees and lawns, is expected to induce a cooling effect by increasing the latent heat flux (E) from the transpiring plants. However, there is nearly no information on direct assessment of plant, and particularly of trees transpiration to the total latent heat flux of a city center.

The aim of this study is to estimate the latent heat flux emitted by a lawn surface (E_L) and isolated linden trees (E_T) in the city centre of Strasbourg (France), and to characterize the seasonal evolution of these fluxes with respect to atmospheric variables.

2. MATERIAL AND METHODS

Study site

The study is conducted in the Historical Garden of the Strasbourg University, France (48°35'04.4"N 7°45'47.8"E).

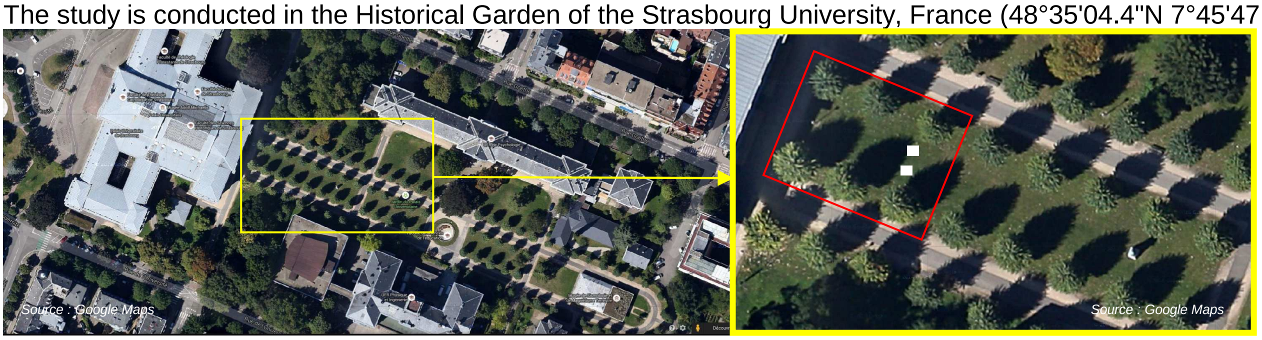

Figure 1. *Study site within the Historical Garden (yellow frame) and location of the six studied sites (red frame). The two white squares indicate the measurement location of lawn transpiration.*

Six adult linden (*Tilia tomentosa* Moench) trees are grown in an urban park in two rows. Mean height and stem diameter at breast height are 10 m and 30 cm, respectively. On a given row, the tree crowns are spaced by c.a. 3 m. Between the rows (c.a. 7 m), a common lawn is grown. A weather station measuring continuously the global radiation, air temperature and relative humidity is installed at c.a. 300 m from the studied site. These values were used to calculate the potential evapotranspiration (PET) according to the Turc formula (Lebourgeois and Piedallu, 2005).

Individual tree transpiration measurements

The total tree transpiration of an individual tree can be assumed as equivalent to the total water flux transiting within the sapwood (Φ_{SW}). Thus crown transpiration of the silver lindens was measured by the thermal dissipation method (Granier, 1985, 1987). The sap-flow sensors consist in two T-type thermocouples (TDTP-30 model, UP GmbH, Cottbus, Germany), inserted entirely within the most external zone of the sapwood in the radial axis, and placed *ca*. 15 cm away from one another vertically. The above thermocouple is heated by a 34.5-Ω-resistant wire, powered for delivering a constant power of 0.2 W. The heated zone is 2-cm long, protected by a 2-mm diameter aluminium tube. The below thermocouple was unheated. Each tree was equipped with one sensor, inserted at breast height (1.3 m) in the north side of each trunk, and protected by an insulating cover, in order to minimize disturbances from externals heat sources. The differential signal from the two thermocouples is recorded half-hourly by a CR1000 datalogger coupled to an AM16/32B multiplexer (Campbell Sci. Inc., UK).

The sap flux density (ϕ_M, in dm^3 m^{-2} s^{-1}) was calculated as

$$\phi_M = 118.99\ 10^{-6}\ k^{1.231} \quad (1)$$

where k is related to the differential temperatures (ΔT, in °C) given by the sensors:

$$k = (\Delta T_{max} - \Delta T)/\Delta T \quad (1)$$

with ΔT_{max} is the maximal differential temperature for a given day, generally reached by the end of the nocturnal phase (Granier, 1985).

The measured ϕ_M values are expressed per sapwood surface area unit. In order to estimate the total sap flow Φ_{SW}, it is necessary to integrate ϕ_M on the entire sapwood surface area (A_{SW}). But from tree to tree the ratio between the sapwood and the heartwood can strongly vary and should be measured. Gebauer et *al*. (2008) established a relationship (n = 21, r^2 = 0.65) between the sapwood area and the diameter at breast height (DBH) on a close linden species, *Tilia cordata* L.:

$$A_{SW} = 2.635\ \mathrm{DBH}^{1.561} \quad (3)$$

We determined then the sapwood width of the studied trees from the DBH values and the calculated A_{SW}. The sap flux density ϕ_M is not constant along the radial axis. Gebauer et al. (2008) proposed a function expressing the relative sap flux density (φ_{SW}) at a relative sapwood depth position. We used this function to estimate the relative contribution of measured sap flux by the probes to total sap flux over the sapwood width Φ_{SW}. The Φ_{SW} are expressed in L s^{-1}, and converted in latent heat flux (E_T, in kJ s^{-1}) by multiplying Φ_{SW} by the latent heat of vaporization of water value, *i.e.* λ = 2480 J g^{-1} (Monteith and Unsworth, 1990). Total tree transpiration are then expressed by crown projected surface area basis. Tree transpiration was monitored during the growing season in 2013 and 2014. From the E_T values, we computed the canopy conductance (g_C) inverting the Penman-Monteith equation following Granier *et al*. (1996).

Lawn transpiration measurements

The transpiration from the surrounding lawn was measured on two locations between the two linden rows (Figure 1) using a closed, transparent chamber system. Air mixing within the chamber is done by fans placed within the chamber at the lawn level. Air temperature and relative humidity were recorded for 2 minutes by a HC-2 S3 probe (Rotronic AG, Bassersdorf, Switzerland). The rate of increase of air water vapor partial pressure within the chamber was deduced and converted into latent heat flux (E_L). The E_L values were determined every 20 minutes from 7:00 to 14:00 (solar time) from June to August 2014.

3. RESULTS AND DISCUSSION

3.1 Daily variations

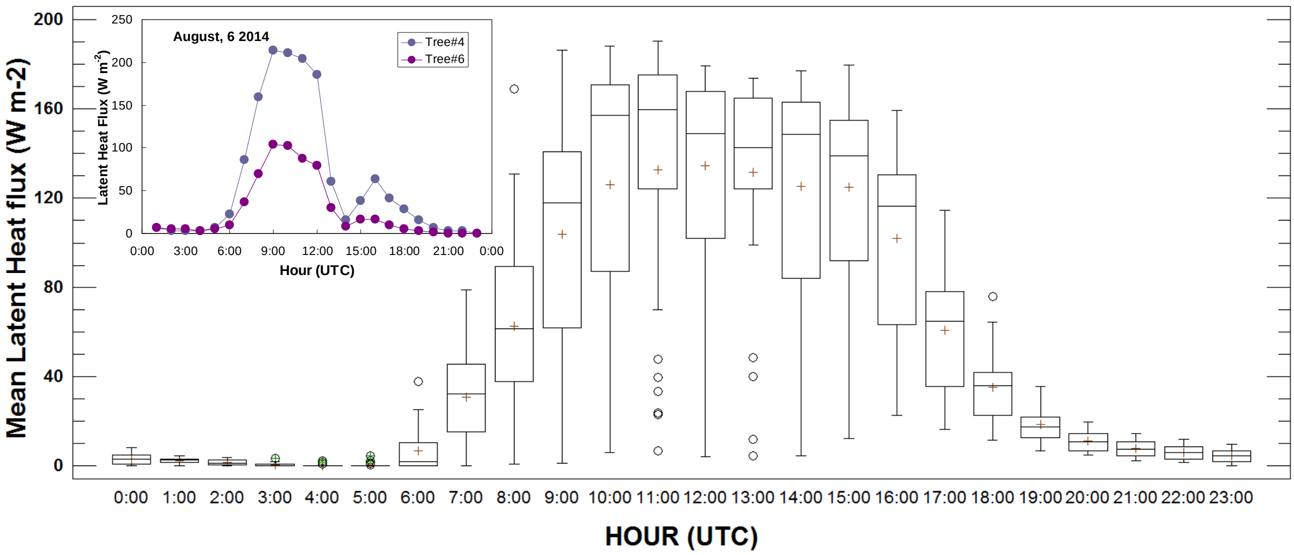

Figure 2. *Daily variations of mean linden crown transpiration in August 2013. The E_T values of the six trees during the entire month were averaged hourly. For each hour, the inferior and superior horizontal lines of the box indicate the first and third quartile of the dataset, respectively. The vertical bars indicate the extreme values. The red cross indicates the mean average, while the horizontal line inside the box indicates the median value. The insert gives an example of daily variations of E_T at a given date for the two most contrasted trees.*

During the growing season, the E_T varied daily (Figure 2). The maximum E_T values were reached in August (2013) and June-July (2014). These maxima varied among trees, ranging from 183 W.m^{-2} to 284 W.m^{-2} (2013), and from 158 W.m^{-2} to 451 W.m^{-2} (2014). As for the trees, the lawn E_L values varied daily (Figure 3A). The maximum E_L values were reached in July 2014, and ranged from 290 W.m^{-2} to 302 W.m^{-2}. **The order of magnitude of E_L and E_T were similar** (Figure 3B).

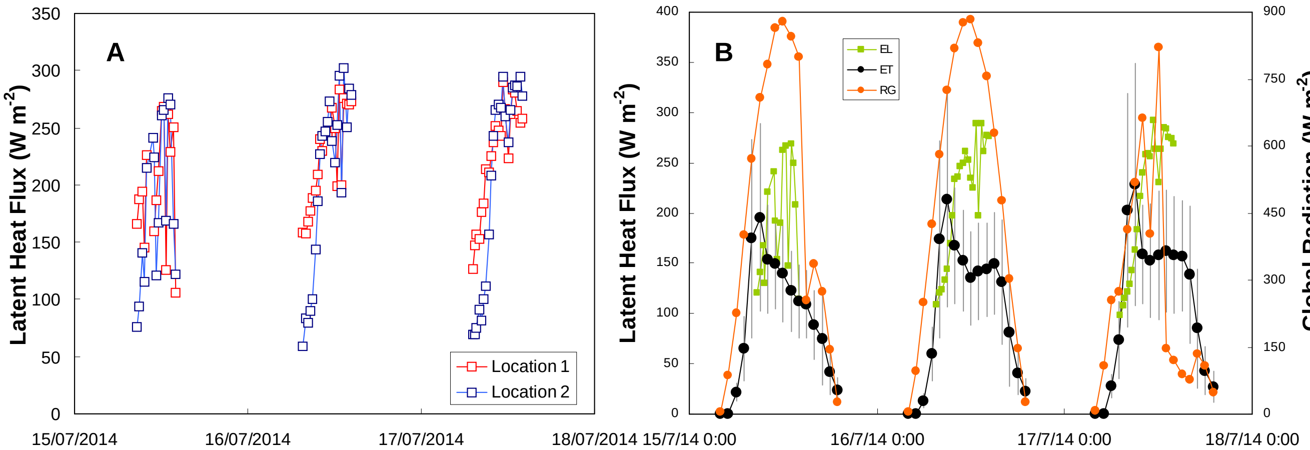

Figure 3. A- *Daily variations of lawn E_L during three successive days in July 2014, at two locations by means of the transpiration chamber. Each E_L data was determined from a 2-min measurement period.* ***B-*** *Comparison of the mean E_L (green) and the mean E_T (black) daily variations during three consecutive days in July 2014 according to the daily variation of the global radiation (orange). The grey bars are the standard deviation of E_T over the six linden trees.*

We can observe contrasted daily patterns between the linden trees and the lawn (especially after solar midday), which can be attributed to a different regulation of leaf transpiration by the stomata (Figure 4A). Most of the daily variations of E_T can be explained by daily variations of both air temperature and air water vapor partial pressure, which can be synthesized as vapor pressure deficit (VPD, Figure 4B).

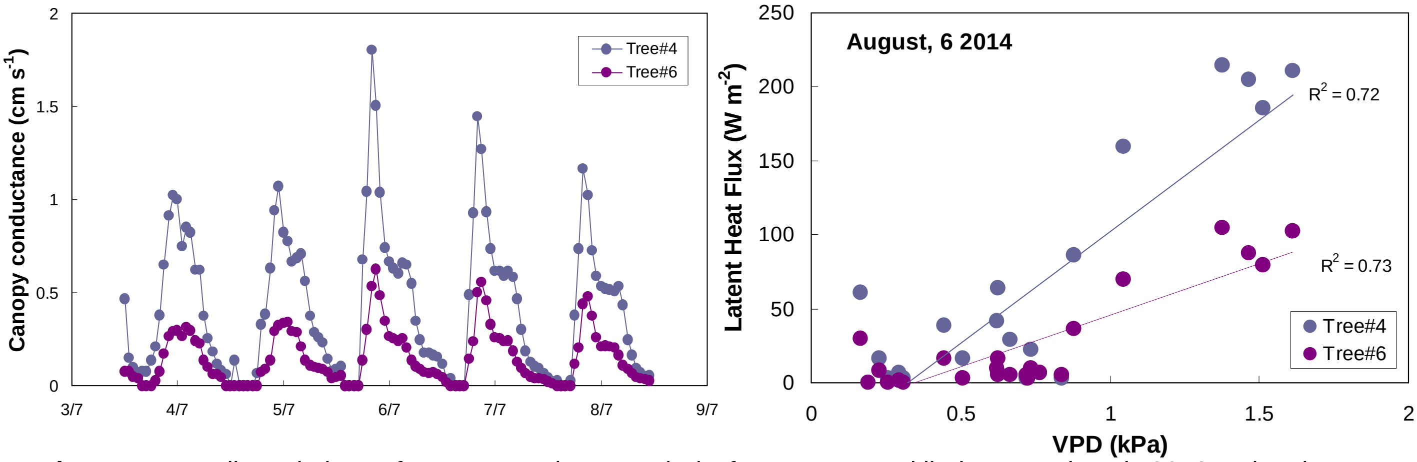

Figure 4. A- *Daily variations of canopy conductance (g_C) of two contrasted linden trees in July 2013, using the inverted Penman-Monteith equation.* ***B-*** *Relationship of E_T and air VPD for two contrasted trees for a given day.*

3.2 Seasonal variations of the linden E_T

The E_T values varied throughout the seasons (Figure 5). The tree phenology strongly affected this pattern: through the development of the leaf area (the budburst occurring in *c.a.* early April) and leaf fall occurring *c.a.* mid-November. As for the daily pattern, the E_T values were well related to mean daily VPD in summer (R^2 = 0.83). The E_T/PET ratio increased from budburst to mid-June according to leaf area development (Figure 6). The ratio remained rather steady within the 0.3-0.4 range and 0.1-0.2 for tree #4 and tree #6 respectively until October. This relative stability indicates that E_T varied according only to atmospheric variables. Such values are lower than those found for forest canopies (Granier et al., 1996; Vincke et al., 2005; Zweifel et al., 2006), probably due to (i) the PET computations which use variables not measured at the same scale/location than for local tree transpiration, (ii) the errors in the estimates of crown projected surface areas. In late August and autumn, the E_T/PET dropped below 0.1 during several days, indicating a possible stomatal regulation of E_T in response to both high atmospheric evaporative demand and some soil water limitation (Figure 6 insert). The daily variations in diameter measured on these trees, which reflect their hydric status dynamics, did not show any significant bark shrinkage, especially during the days of reduced E_T/PET ratio (data not shown). This would indicate a strong regulation of stomata, **allowing the studied silver linden to avoid strong hydric stresses in their growing conditions**. Further analyses will be conducted to better assess the water balance dynamics in this urban park. In a near future, the measured values of linden and lawn transpiration will be used for (i) validating latent heat fluxes estimated by the eddy correlation method on the same location, and (ii) to better assess the tree functioning in response to environmental variables of an urban ambient.

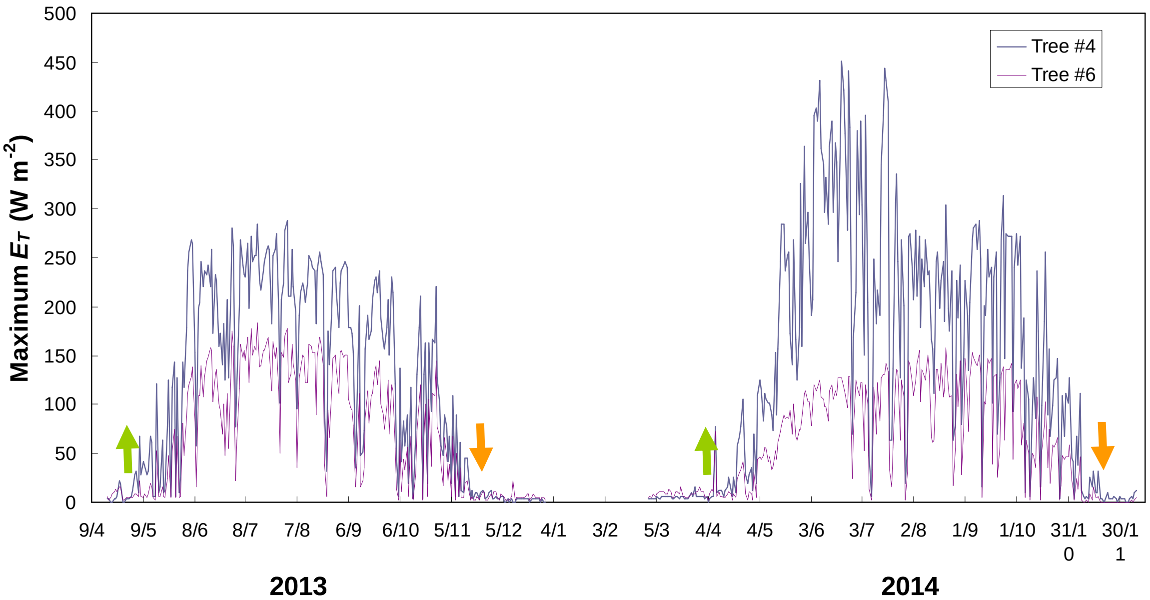

Figure 5*. Seasonal variations of the daily maximal E_T for two contrasted linden trees. The green arrows indicate the budburst and the orange ones indicate the leaf fall.*

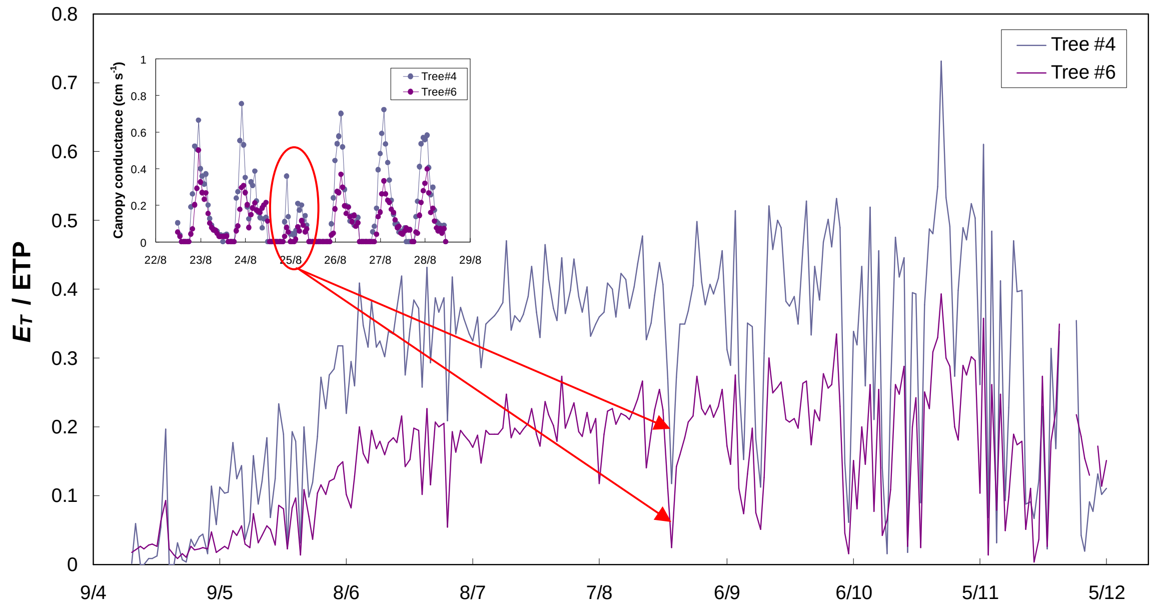

Figure 6*. Seasonal variation of the E_T/ETP ratio (in 2013) for two contrasted linden trees. The insert illustrates the canopy conductance g_C evolution at the end of August 2013, highlighting the g_C decrease (25 August) coinciding with a strong decrease of the E_T/PET ratio.*

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