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Response of the Sapflux Density and Decoupling Coefficient of Deciduous and Coniferous Species to Wind Speed and their Effects on Air Temperature Reduction

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I. Introduction

Plant water loss via transpiration is controlled largely by four main environmental parameters, which are radiation, air temperature, vapor concentration, and wind speed. Among them, wind speed controls the external resistance or boundary layer resistance in water vapor pathway. Increasing wind speed directly increases the transpiration by reducing the thickness of boundary layer of water vapor surrounding the leaves. On the other way, increasing wind speed indirectly decreases the transpiration by leaf cooling due to more efficient convection. This bidirectional effect of wind speed on transpiration causes the variable results in the relationship between wind speed and transpiration rate. Some authors have reported that transpiration may respond negatively to increasing wind speed by measurements (Dixon and Grace, 1984) and by mathematical or modelling approaches (Schymanski and Or, 2015). However, general expectation is still that increasing wind speed causes the transpiration increased due to positive relationship between wind speed and atmospheric water vapor demand (Jolliet and Bailey, 1992; McVicar *et al.*, 2012; McMahon *et al.*, 2013).

The negative impact of wind speed on transpiration may be caused by tight stomatal regulation under high wind speed. Increasing transpiration demand with wind speed causes the higher leaf water stress under high wind speed. This makes plants close their stomata to keep the leaf water potential and results in higher stomatal resistance with increasing wind speed. The stomatal resistance is controlled by size and density of stomata and the stomatal sensitivity against changes of environmental conditions, which shows large interspecific variation (Oren *et al.*, 1999). In addition, boundary layer resistance also shows large interspecific variation. It depends largely on wind speed and on the leaf size and shape. The size and shape of leaf determine the leaf characteristic length, which means the length that wind pass though leaf. The wide variance

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in size and shape of leaves among species causes the interspecific differences in sensitivity of boundary layer resistance with wind speed.

The relative importance in controlling transpiration of stomatal and boundary layer resistance can be summarized by decoupling coefficient (Ω). It varies from 0 (a perfect coupling between boundary layer and atmosphere, transpiration is dominantly controlled by boundary layer resistance) to 1 (a complete isolation between boundary layer and atmosphere, transpiration is dominantly controlled by stomatal resistance).

Transpiration increases energy partitioning ratio to latent heat flux and reduces surface temperature. Due to increasing concern in increasing air temperature and related heat stress, mitigating the heat stress through plant transpiration gains more attention. Thus, this study focuses on (1) the effects of wind speed on transpiration of tree species with different leaf characteristic length, and (2) on quantifying the transpirational cooling effect and finding the factors controlling the cooling effect.

II. Materials and Methods

Tree species were chosen to cover wide range of leaf characteristic length. Selected species were 3 broadleaved species (*Cornus kousa* (COKO), *Prunus serrulata* (PRSE) and *Magnolia Kobus* (MAKO)) and 2 coniferous species (*Pinus koraiensis* (PIKO) and *Abies holophylla* (ABHO)). The leaf characteristic length was longest on MAKO (10.07 ± 0.19 cm) and shortest on ABHO (0.67 ± 0.02 cm). Tree-level transpiration was scaled up from sap flux density measured by Granier type thermal dissipation probe method (Granier, 1987). Measurements were performed on indoor wind tunnel where air movement was controlled by extractor fan. Wind speed was changed from 1 m s^{-1} to 4 m s^{-1}. Each tree was exposed to same wind speed for 30 min and rested for 20 min before changing the wind speed. Photosynthetically active radiation was generated by artificial LED light source to produce a constant light condition. Air temperature and vapor pressure deficit were not controlled, but the experiments were repeated random species order to minimize the initial difference in environmental conditions among species. Before the measurement, each tree was irrigated sufficiently to minimize water stress during the wind tunnel experiments. Air temperature was measured in front and back of the tree at 4 heights and the average air temperature difference was considered as transpiration-induced temperature reduction. After wind tunnel experiment, all leaves were collected to measure average leaf characteristic length and total leaf area.

III. Results

3.1. Effects of wind speed on sapflux density

In all species, sapflux density and leaf-level transpiration increased with wind speed (Fig. 1a). Leaf-level transpiration was also increased with wind speed, and species with longer leaf characteristic length showed higher sensitivity to wind speed (Fig. 1b). Broadleaved species showed higher transpiration than coniferous species.

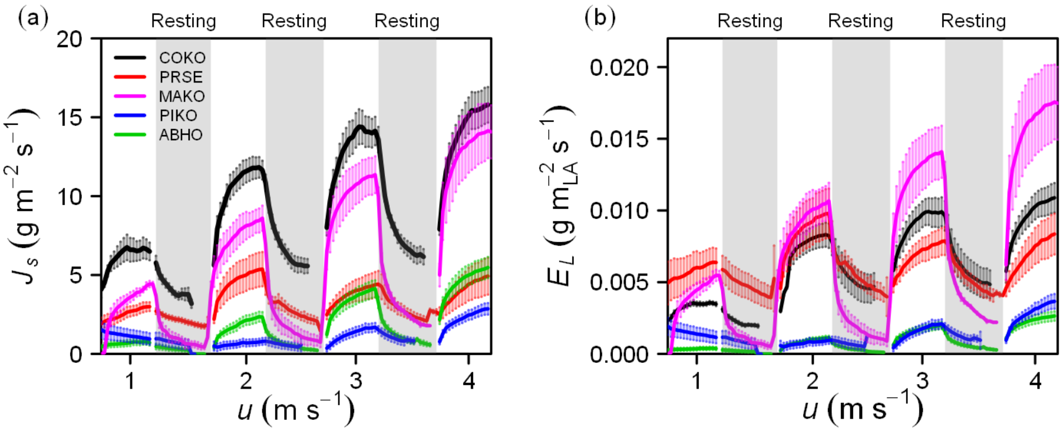

Fig. 1. Effects of wind speed on (a) sapflux density (J_s) and (b) leaf-level transpiration (E_L) of *Cornus kousa* (COKO; black), *Prunus serrulata* (PRSE; red), *Magnolia Kobus* (MAKO; pink), *Pinus koraiensis* (PIKO; blue) and *Abies holophylla* (ABHO; green). Vertical bars indicate the standard errors.

3.2. Transpiration-induced temperature reduction

Transpiration made the air temperature reduction in all circumstances. This transpirational cooling effect was positively correlated with total transpiration in the coniferous species, but not in the broadleaved species (Fig. 2a). However, broadleaved species showed the negative correlation between transpirational cooling effect and decoupling coefficient (Fig. 2b). There were large interspecific variations in decoupling coefficient, which showed the interspecific difference in sensitivity of boundary layer resistance against wind speeds. High decoupling coefficient indicates the formation of thick boundary layer, which weaken the relationship between total transpiration and the cooling effect, and makes smaller cooling effects than low decoupling coefficient species.

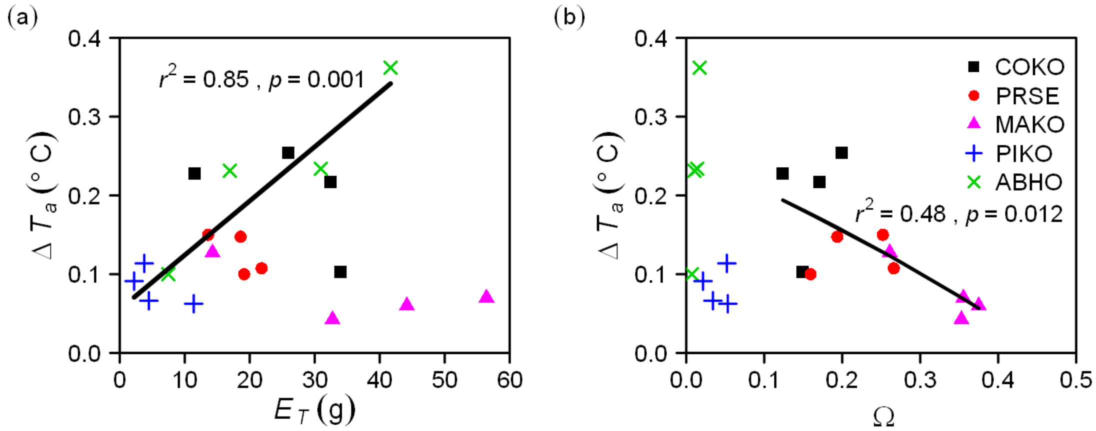

Fig. 2. The effects of (a) total transpiration (E_T) and (b) decoupling coefficient (Ω) on transpiration-induced air temperature reduction (ΔT_a) of *Cornus kousa* (COKO; black square), *Prunus serrulata* (PRSE; red circle), *Magnolia Kobus* (MAKO; pink triangle), *Pinus koraiensis* (PIKO; blue cross) and *Abies holophylla* (ABHO; green x). Black lines indicate the linear regression lines between (a) total transpiration and the temperature reduction of coniferous species, and (b) decoupling coefficient and the temperature reduction of broadleaved species.

Our results showed that there were differences in controlling the cooling effect between broadleaved species and coniferous species. In coniferous species which have thin boundary layer, transpiration rate was the dominant factor in temperature reduction, but in broadleaved species which have thick boundary layer, the degree of decoupling explained the amount of the temperature reduction.

References

Dixon, M., and J. Grace, 1984: Effect of wind on the transpiration of young trees. *Annals of Botany* **53**, 811-819.

Granier, A., 1987: Evaluation of transpiration in a douglas-fir stand by means of sap flow measurements. *Tree Physiol* **3**, 309-319.

Jolliet, O., and B. J. Bailey, 1992: The effect of climate on tomato transpiration in greenhouses: measurements and models comparison. *Agricultural and Forest Meteorology* **58**, 43-62.

McMahon, T., M. Peel, L. Lowe, R. Srikanthan, and T. McVicar, 2013: Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis. *Hydrology and Earth System Sciences* **17**, 1331-1363.

McVicar, T. R., M. L. Roderick, R. J. Donohue, L. T. Li, T. G. Van Niel, A. Thomas, J.

Grieser, D. Jhajharia, Y. Himri, and N. M. Mahowald. 2012: Global review and synthesis of trends in observed terrestrial near-surface wind speeds: Implications for evaporation. *Journal of Hydrology* **416**, 182-205.

Oren, R., J. S. Sperry, G. Katul, D. E. Pataki, B. Ewers, N. Phillips, and K. Schäfer, 1999: Survey and synthesis of intra-and interspecific variation in stomatal sensitivity to vapour pressure deficit. *Plant Cell Environ* **22**, 1515-1526.

Schymanski, S. J., and D. Or, 2015: Wind effects on leaf transpiration challenge the concept of ‘potential evaporation’. *Proceedings of the International Association of Hydrological Sciences* **371**, 99-107.