Environmental controls on growing-season sap flow density of *Quercus serrata* Thunb in a temperate deciduous forest of Korea

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Abstract

Sap flux density (SFD) measurements were used, in combination with morphological characteristics of trees and forest structure, to calculate whole-tree transpiration, stand transpiration (St) and mean canopy stomatal conductance (Gs). Analysis based on the relationships between the morphological characteristics of trees and whole tree water use, and on the responses of SFD and Gs to short wave radiation (RR), vapor pressure deficit (VPD) and soil water content (SWC) during drought and non-drought periods were conducted. The results showed a strong positive correlation between whole tree transpiration and both tree diameter at breast height (DBH) ($r^2 = 0.95$, $P < 0.05$) and sapwood area (SA) ($r^2 = 0.98$, $P < 0.05$). Relationships between SFD and DBH ($r^2 = 0.25$), as well as SA ($r^2 = 0.17$) were weak. Daily SFD of *Quercus serrata* Thunb was closely related to VPD and RR. Although operating at different time scales, RR and VPD were important interacting environmental controls of tree water use. SFD increased with increasing VPD (<1 kPa) and RR. SWC had a considerable effect on stand transpiration during the drought period. The relationships between SFD, VPD and RR were distorted when SWC dropped below 35%.

Key words: drought effect, sapflow, stand transpiration, *Quercus serrata*

INTRODUCTION

In East Asia, precipitation is concentrated in the short monsoon period between July and August, leaving the rest of the year mostly dry, and limiting the availability of water to trees since most of the soil water store is rapidly depleted (Shin 2002, Hwang et al. 2008). In South Korea, most forests are located in mountainous areas which experience rapid lateral water flux, as well as uneven distribution of soil water, further adding to the forest trees vulnerability to drought. In areas where precipitation exceeds potential evaporation, annual water use by trees equals cumulative transpiration, which depends on atmospheric conditions and their interactions with stomatal conductance, canopy architecture and leaf area (Landsberg and Gower 1997). When water in the rhizosphere is limiting, to the extent that root water uptake cannot cope with transpirational demands, then trees will respond by closing their stomata in order to limit the drop in tissue water potentials to dangerous levels that could cause cavitation of the conducting vessels (Sperry and Pockman 1993, Cochard et al. 1996).

Transpiration is a major contributor to water loss in forests (O’Grady et al. 2008), constituting a major hydrologic
component of the montane-forested catchments, and its quantification is critical for water resource management. The accurate estimation of tree transpiration is however difficult, particularly in rugged mountainous terrain. The sap flow technique is a useful tool for investigating forest water use i.e., transpiration at temporal and spatial scales (Ford et al. 2007, Kumagai et al. 2007, Jung et al. 2011). In recent years, measurements of water use at the individual tree level have become more widespread, due to the development of reliable sap flow techniques (Granier 1985, Köstner et al. 1998, Dierick and Höltscher 2009). A common approach for estimating transpiration is based on the measurement of sap flux density (SFD) by the Thermal Dissipation Probe method (Granier 1987, Oren et al. 1998). The sap flow based canopy conductance (Gs) can provide a way of relating Gs to environmental factors, and help to explain the mechanism of water use of forest in different habitats. Sap flow measurements can distinguish transpiration among individuals and among class in the stand.

Understanding how transpiration varies according to climate factors as well as soil water content (SWC) is vital in forest hydrology studies. Variation in sap flow rates is explained on the basis of variation of different environmental controls, such as heterogeneity in soil water conditions, vapor pressure deficit (VPD), short wave radiation (RR) and also on the basis of methodological differences in sap flow measurements. Implications of temporal water shortage on temperate forest trees with respect to leaf water status (Hinckley et al. 1981), stomatal conductance, photosynthesis (Epron and Dreyer 1993) and hydraulic conductivity (Bréda et al. 1993, Cochard et al. 1996) have been studied extensively. It was shown that tree sap flow rates scaled to the stand level plus evapotranspiration from soil and the understory agreed with water vapor fluxes measured above the forest canopy with the eddy-correlation techniques (Granier et al. 1996, Köstner et al. 1998). In the course of a drought, gradually decreasing stomatal conductance, pre-dawn leaf water potential, assimilation and growth are commonly observed, accompanied by a stimulation of fine root growth (Leuzinger et al. 2005). With regard to water deficits, Scots pine closes stomata when the soil water deficit has reached a specific threshold (Irvine et al. 1998), whereas pubescent oak maintains high transpiration rates despite the incidence of drought (Nardini and Pitt 1999), partly due to an ability to extract water from deep soil layers and groundwater (Valentini et al. 1992).

An improved understanding of how environmental factors, particularly SWC, RR and VPD influence stand transpiration is necessary in order to predict how these temperate forests may respond to the predicted reductions in precipitation due to climate change. In this study, we examined how the regulation of transpiration in individual trees responded to changes in SWC. We selected the tree species, *Quercus serrata*, because it is widely distributed in lowland forested areas of the Korean Peninsula. We hypothesized that there exists a SWC threshold, which determines critical SFD values under conditions of limited soil water supply. The main objectives of this study were 1) to relate the variability in sap flow to environmental variables; 2) to determine daily and seasonal patterns of stand transpiration, and 3) to investigate how drought affects tree sap flow, and stand transpiration.

**MATERIALS AND METHODS**

**Study site**

The study site was at Gwangneung Experimental Forest (GN) located in central western part of the Korean Peninsula (37°44′N and 127°9′E), and the elevation of the site is 330 m above sea level. The Korean peninsula is located on the boundary between polar and tropical climates, and is strongly influenced by a continental air mass. During winter, strong continental high-pressure systems develop over Siberia, bringing dry cold air to Korea. In summer, monsoon brings southerly winds and abundant moisture from the ocean. Precipitation is concentrated in summer period, with 45-60% of the total annual rainfall occurring in summer, and 3-10% in winter.

A flux tower was constructed at the site in order to monitor changes in carbon/energy fluxes within the microclimate since 2001 (Lee et al. 2007). The density of the trees was 1,473/ha with a total biomass of 261 ton/ha, while the basal area was 28 m²/ha. The site was dominated by *Quercus serrata* (51% of total basal area), followed by *Carpinus laxiflora* (23% of total basal area). *Quercus serrata* is the most common tree species in Korea. Based on tree location, size, and stem structure, 6 trees of *Quercus serrata*, were chosen for sap flow measurements. Our strategy was to measure sap flow in trees with a range of diameter at breast heights (DBHs), so as to ensure that the entire stand was represented. In the study year 2007, the growing season for deciduous trees lasted from the beginning of April (bud break) to the beginning of November. The measurements were started in May 2007 and continued till November, 2007.