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Constraints on transpiration of *Eucalyptus globulus* in southern Tasmania, Australia

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ABSTRACT

The constraints on transpiration were studied in plantation grown *Eucalyptus globulus* trees over the summer of 2004/2005 at a research site in southern Tasmania. Diurnal patterns of leaf water potential and tree water use, measured using heat pulse techniques, were examined monthly in rain-fed and irrigated trees growing under similar atmospheric conditions. Soil matric potential declined during the summer in rain-fed plots but remained high in irrigated plots. Pre-dawn leaf water potentials decreased in rain-fed trees and this was associated with increasing soil water deficit. The difference between pre-dawn and midday leaf water potential declined with decreasing pre-dawn water potential, suggesting isohydric regulation of plant water potential. Transpiration and canopy conductance were lower in rain-fed trees than irrigated trees and the decline in transpiration and canopy conductance was related to pre-dawn leaf water potential. There was marked hysteresis in the relationship between transpiration and *D* in both rain-fed and irrigated trees. Hysteresis was also observed in the relationship between transpiration and leaf water potential. However, in this case hysteresis was only evident in rain-fed trees. For the relationship between transpiration and *D*, hysteresis was larger at high *D*'s than at low *D*'s in both rain-fed and irrigated trees and was not related to diurnal changes in soil to leaf hydraulic conductance. Diurnal changes in leaf conductance, however, may play an important role in controlling stomatal sensitivity to *D* and may help to explain the hysteresis in the relationship between transpiration and *D*. Soil-to-leaf hydraulic conductance of rain-fed trees declined in response to decreasing pre-dawn leaf water potential. We propose that loss of hydraulic conductance is an important mechanism for explaining increasing stomatal control of transpiration under progressive soil drying.

1. Introduction

Eucalyptus globulus (Labill.) is a plantation tree species of international significance (White et al., 1998; Shvaleva et al., 2006). Within Australia, as in other parts of the world, the rapid expansion in the area of *E. globulus* plantations (White et al., 2003; Macfarlane et al., 2004) has generated concern about risks associated with susceptibility to drought (White et al., 2003), as well as the potential environmental consequences, in particular the effects of plantations on regional water balance

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(David et al., 1997; Whitehead and Beadle, 2004). These have driven a need to better understand the processes driving the growth and productivity of this species.

E. globulus is a highly productive, drought tolerant species (David et al., 1997). Leaf physiology in this species has been studied intensively and atmospheric controls on transpiration have been well characterised (White et al., 1996, 1998, 1999, 2000). Many of these insights have been incorporated into process-based models of growth and productivity for this species (e.g. Cabala, Battaglia et al., 2004). In these models, the sensitivity of stomatal conductance (g_w) to vapour pressure deficit (*D*) is central to estimating plant water use and carbon gain. However, the relationship between stomatal conductance and *D* is largely empirical (Monteith, 1995). Mott and Parkhurst (1991) suggest that the decline in stomatal conductance in response to increasing *D* is related to increasing transpiration rate (*E*) and decreasing leaf water potential rather than stomatal sensing of *D*, *per se*. Thus, it has been suggested that stomata close to reduce water loss and maintain leaf water potentials above a critical threshold that prevents catastrophic loss of xylem function (Salleo et al., 2000; Sperry, 2000; Cochard et al., 2002; Brodribb et al., 2003; David et al., 2004).

These insights have led to considerable effort being focused on examining the hydraulic constraints on gas exchange (Tyree and Ewers, 1991; Tsuda and Tyree, 1997; Sperry, 2000; Williams et al., 2001; Sperry et al., 2002; David et al., 2004). These have demonstrated that hydraulic conductance of the pathway from the soil to the leaf is an important determinant of leaf water potential, and thus, leaf turgor and growth (Tyree, 2003). Despite this, very few process-based models of tree growth incorporate a consideration of tree hydraulics (but see for example Williams et al., 2001). An improved understanding of the role of tree hydraulics on plant water relations will help to improve not only assessments of drought vulnerability, but also provide a better framework for understanding plantation water uptake and thus water use efficiency. Furthermore, if models are to be useful for indicating the potential for selecting genetic material or manipulating management to maximise water use efficiency, this fuller system representation is critical (Tyree, 2003; Whitehead and Beadle, 2004).

In the current study, we examined diurnal patterns of leaf water potential, vapour pressure deficit (*D*) and transpiration in young (<3 years old) rain-fed and irrigated *E. globulus* trees growing at the same site and under similar atmospheric conditions. The aim was to better understand of the relative importance of atmospheric and hydraulic controls on plant water use. In particular, we examined minimum daily leaf water potentials in rain-fed and irrigated trees under a range of vapour pressure regimes and under a range of soil water deficits to determine whether *E. globulus* trees exhibit isohydric regulation of plant water status. We were also interested in exploring whether changes in soil-to-leaf conductance could explain the commonly observed hysteresis in the relationship between *E* and *D*. Finally, we sought to quantify the changes in soil-to-leaf conductance associated with increasing soil water deficits.

2. Methods

2.1. Site description

Research was conducted at the Pittwater research plantation (42°94′S, 147°30′E) approximately 20 km east of Hobart in south-east Tasmania over the 2004–2005 summer (November 2004 to January 2005). This plantation was established in September 2002 and trees at the site were approximately 2.5 years old. The climate of the region is classified as cool temperate maritime, with an average rainfall of approximately 500 mm per year and annual pan evaporation in excess of 1300 mm per year. Mean daily maximum and minimum temperatures vary between 22.5 and 12.5 °C and 12 and 4 °C for summer and winter, respectively (Bureau of Meteorology, www.bom.gov.au). Soils were duplex (Podosol, Isbell, 1996) with a 1.5–2.0 m deep Aeolian derived sandy A-horizon overlying a sandy-clay to clay B-horizon (bulk density of the A horizon approximately 1.4 g cm^{-3}).

The site consisted of nine growth plots comprising three experimental treatments replicated using a three-way Latin-square design. The three treatments were imposed from establishment and related to irrigation regimes. Control plots were not irrigated (rain-fed) and trees were totally reliant on; rainwater, soil water or groundwater for their water-use requirements. The two imposed irrigation treatments were; irrigation to both sides of the tree (full irrigation) and irrigation to only one side of the tree (partial root drying treatment). In the current study, only two treatments have been used; the control (rain-fed) and the full irrigation treatment. Irrigation was applied to ensure a relatively uniform supply of soil water throughout the soil profile. An irrigation event equivalent to 6 mm of irrigation was applied every second night throughout the course of the experiment. Each growth plot was 225 m^2 and contained 25 trees, planted on a 3 m × 3 m spacing (equivalent to 1111 stem ha^{-1}). Above- and below-ground growth has been monitored at the site since inception (O'Grady et al., 2005, 2006a,b). During the measurement period, trees were approximately 7.0 m high with a diameter at 1.3 m of 7.3 cm. Leaf area index was approximately 3.0.

2.2. Climate

Climate was monitored using an automatic weather station, installed in an open field approximately 100 m north-west of the plantation. Temperature and humidity were measured using a temperature/humidity probe (Vaisala HMP35A, Helsinki, Finland) mounted 1.5 m above ground level (a.g.l.) inside a Stevenson screen. Rainfall was measured using a tipping bucket rain gauge, 200 mm diameter and 0.2 mm per tip (Monitor Sensors TBRG Qld., Australia). At 2.0 m a.g.l, total radiation was measured using a Licor LI200X pyranometer (Nebraska, USA), wind speed and direction were also measured using a Met One 014A anemometer (Oregon, USA). Climate data were integrated every minute. Thirty-minute averages or total (rainfall) were recorded using a Campbell CR10 data logger (Utah, USA). Vapour pressure deficit (*D*) was calculated from relative