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CANOPY CONDUCTANCE AND WATER USE IN *EUCALYPTUS* PLANTATIONS

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Abstract

Previous studies have shown leaf water efficiency (transpiration per unit of leaf area) to be similar among trees and stands of different *Eucalyptus* species in similar soil and climatic conditions. On the other hand, leaf water efficiency may vary widely among stands in different regions. The present study compares young plantations of a single species (*Eucalyptus camaldulensis* Denhn.) on two sites with contrasting conditions in Australia and Pakistan, to examine the nature of differences in leaf water efficiency and the factors that cause it. Tree water use was measured on up to 28 trees per site over 12 months using heat pulse equipment with a 30 minute sampling interval and logging period of 3-4 weeks per tree. Observations of climate and soil parameters were also recorded automatically at 30 minute intervals. Water use over a 12 month period was 1160 mm at Pacca Anna (Pakistan) and 310 mm at Girgarre (Australia). This is predominantly a result of higher sap flux density (and hence leaf water efficiency) at Pacca Anna. Sap flux density at Girgarre reached its maximum value at a daily mean vapour pressure deficit of approximately 1.2 kPa, but at Pacca Anna sap flux density continued to increase at daily mean vapour pressure deficit of up to 6 kPa. Greater hydraulic conductivity of the sandy soil at Pacca Anna, or higher rhizospheric conductance into a more extensive root system, also do not account for the observed differences in the vapour pressure deficit at which transpiration is a maximum. The results imply that the slope of the decline in stomatal conductance with increasing vapour pressure deficit differs between sites, although maximum stomatal conductance is the same. Variations in leaf water efficiency between sites may arise from the influence of environmental factors such as air or soil temperature on stomatal functions, possibly mediated by hormonal responses.
Keywords: sap flux density, transpiration, salt tolerance, stomatal conductance

Introduction

Salt-affected soils and saline groundwater are a serious concern of agriculture world-over. A permanent solution to the salinity problem involves removal of excess salts by leaching with good quality water and drainage. However, this approach cannot be applied on vast areas due mainly to high costs on construction of drainage systems, shortage of good quality water and disposal of saline water, etc. As an alternate, a shift towards saline agriculture and biological remediation of saline lands is recommended (Davidson & Galloway, 1993; Qureshi & Barrett-Lennard, 1998).

Tree growing is an important option and several species are known to provide economic yields of forage, fuelwood, timber and other products from degraded saline

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This paper is dedicated to the memory of Dr. Jim Morris whose painstaking guidance and encouragement has always been instrumental in making the work reported here possible. His untimely death in April 2006 was a great loss for all of us who enjoyed the privilege of working in his supervision, and above all his sincere friendship.

lands. More recently, progress with provenance and progeny screening of successful species has been reported with the objective of improved tree growth and quality (Marcar & Khanna, 1997; Mahmood *et al*., 2003). In addition to improving soil chemical and physical properties, tree plantations have the potential to help control salinity by extracting shallow groundwater or seepage from irrigation channels in low rainfall areas (Khanzada *et al*., 1998). Tree water use (transpiration) is controlled by several factors such as the species, soil conditions and climatic variations. Previous studies (Hatton *et al*., 1998; Mahmood *et al*., 2001) have shown leaf water efficiency (transpiration per unit of leaf area) to be similar among trees and stands of different *Eucalyptus* species growing in similar soil and climatic conditions. On the other hand, leaf water efficiency may vary widely among stands in different regions. The present study compares young plantations of a single species (*Eucalyptus camaldulensis* Dehnh) on two sites with contrasting conditions in Australia and Pakistan, to examine the nature of the difference in leaf water efficiency and the factors that cause it.

Materials and Methods

Experimental sites and plantations: The studies were conducted on Eucalyptus plantations located at Pacca Anna near Faisalabad (31° 15'N, 72° 49'E) Pakistan and, Girgarre (36° 25'S, 145° 00'E) in south-eastern Australia. Both sites are semi-arid with warm summers and cool winters. Annual rainfall during the study period was 370 mm at Pacca Anna and 257 mm at Girgarre. Most rainfall at Pacca Anna falls during the summer monsoon; at Girgarre the distribution is more uniform. The soil at Pacca Anna is deep loamy sand with a water table at 3 to 4 m depth. At Girgarre the soil is medium to heavy clay with water table depth of 1.5 to 3.5 m.

The Pacca Anna plantation was established in 1993 at 2 meter spacing, while at Girgarre planting was done in 1989 at 4 m spacing. Both plantations were irrigated for one or more seasons after establishment, but not during the period of this study and derived part of their water requirement from shallow saline groundwater, with electrical conductivity of approximately 4 dS m^{-1}.

Data collection: Tree water use was measured on up to 28 trees per site by the heat pulse method as described by Edwards & Warwick (1984) and modified by Olbrich (1991). Sapflow loggers from Greenspan Technologies (Warwick, Australia) were used to record apparent heat pulse velocity at four points in the sapwood of each tree at 30 minute sampling intervals for 3-4 weeks. The data were converted to estimates of sap flux density (SFD), i.e. sap flow per unit cross section area of sapwood, using supplementary data. Whole-tree SFD was determined following the area-weighted mean approach of Hatton *et al*. (1990), and multiplied by sapwood area to obtain instantaneous tree water use. The half-hourly water use data were integrated over each day to obtain daily water use. Daily plot water use was estimated as the product of plot sapwood area and mean SFD for the monitored trees. The data presented have been offset 6 months for comparison of seasonal maxima at the two sites.

Stem diameters over bark at breast height (DBH; 1.3 m above ground level) were recorded on all trees at approximately 6 month intervals. Sapwood area of trees selected for water use monitoring or leaf area assessment was calculated from measurements of DBH, bark thickness, and sapwood width assessed from increment cores taken at 2-4 points around the stem (see details in Mahmood *et al*., 2001). Observations of climate and soil parameters were recorded automatically at 30 minute intervals. Canopy conductance (Gc) was calculated from observations of transpiration (E) and vapour pressure deficit (V) as Gc = (γλ/ρCp) (E/V) as described by Morris *et al*. (1998). Regression of sapwood area against DBH was used to estimate the sapwood area of all trees in a plot.

Results and Discussion

Sapwood cross-sectional area of the stands monitored in this study at a height of 1.3 m in 1995-96 was 3.6 to 7.1 m^2 ha^{-1} at Pacca Anna and 5.4 to 6.2 m^2 ha^{-1} at Girgarre, approximately 75% of stand basal area. The trees at Pacca Anna had relatively higher growth rate compared to trees at Girgarre site that seems because of the age difference between two plantations. Young tree stands including *Eucalyptus* spp. are known to have rapid growth up to age 5 years (Mahmood *et al*., 2001). Despite variation in growth rates, the ratio of leaf area to sapwood area was similar at both sites (4700 m^2 m^{-2}). The leaf area and sapwood measurements were linearly related (Fig. 1). Thus, the estimates of transpiration based on sapwood area are valid.

Eucalyptus camaldulensis at Pacca Anna displayed extremely high sap flux density (SFD) during summer that gradually dropped to minimum in winter. In contrast, SFD at Girgarre was markedly lower throughout the monitoring period (Fig. 2). Sap flux density is reported to depend on several factors such as soil, climate, and plant species. Khanzada *et al*. (1998) observed generally similar SFD in *Acacia* and *Prosopis* on a less saline site. In other studies, SFD differed between *A. ampliceps*, *P. juliflora* and *Eucalyptus*. Neither local variations in soil conditions nor climatic variations from year to year appeared adequate to explain these variations (Mahmood *et al*., 2001). Morris & Collopy (1999) reported a decline in SFD of a young *Casuarina* plantation with increasing sapwood area over a 2 year period. The variations in SFD tended to follow the atmospheric vapour pressure deficit (VPD). This observation was very clear at Pacca Anna where a

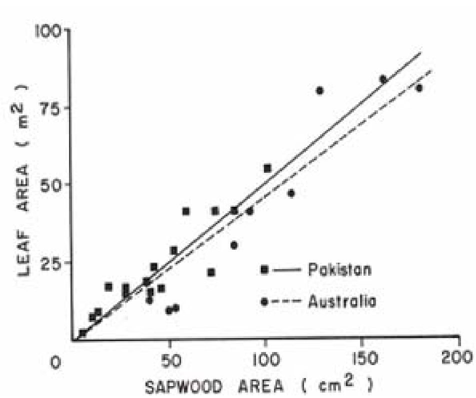

Fig. 1. Relationship between leaf area and sapwood area of *Eucalyptus camaldulensis* trees in the experimental plantations at Pacca Anna (Pakistan) and Girgarre (Australia).

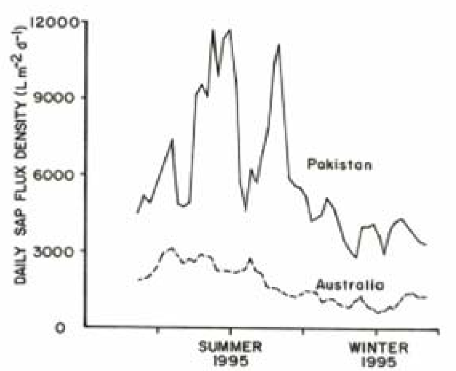

Fig. 2. Daily means of sap flux density (i.e., sap flow per unit cross section area of sapwood) of *Eucayptus camaldulensis* at Pacca Anna (Pakistan) and Girgarre (Australia).

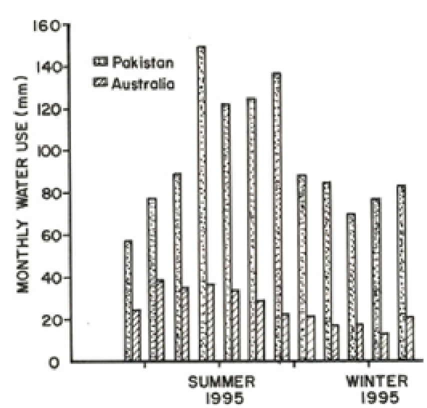

Fig.3. Monthly stand water use of *Eucalyptus camaldulensis* at Pacca Anna (Pakistan) and Girgarre (Australia).

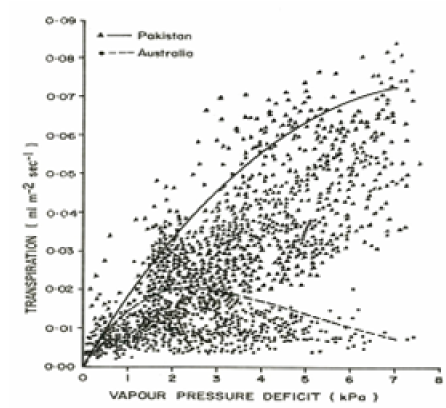

Fig. 4. Relationship between vapour pressure deficit and transpiration between 10 AM to 4 PM calculated from observations of sapflux density of *Eucalyptus camaldulensis* trees at Pacca Anna (Pakistan) and Girgarre (Australia).

sharp decline in SFD was recorded during the monsoon rains. Stand water use also followed a similar pattern as is evident from the monthly water use values (Fig. 3). Water use over a 12 month period was 1160 mm at Pacca Anna and 310 mm at Girgarre. This is predominantly a result of higher SFD (and hence leaf water efficiency) at Pacca Anna. Daily sap flux density at Girgarre reached its maximum value at a mean daily vapour pressure deficit of approximately 1.2 kPa, but at Pacca Anna SFD continued to increase at daily vapour pressure deficit of up to 6 kPa.

Akhter *et al*. (2005) reported that water use and transpiration efficiency of *Acacia ampliceps* and *Eucalyptus camaldulensis* were significantly affected by different soil moisture levels; the latter species showed higher transpiration under well-watered soil. Water flow through the soil-plant-atmosphere pathway is affected by a series of factors, i.e. resistances representing aerodynamic, stomatal, xylem, rhizosphere and soil components. For a detailed comparison, values of transpiration calculated from half-hourly observations of sap flux density were plotted against the water pressure deficit (Fig. 4). Transpiration tended to be linearly correlated with vapour pressure deficit at Pacca Anna. In contrast, transpiration increased with increasing vapour pressure deficit to a certain level (2 kPa) beyond which it dropped gradually. Canopy conductance calculated from the water use data also supported these observations, demonstrating a decline with increasing VPD that was more pronounced for the Girgarre site (Fig. 5). The substantially higher water use (transpiration) by *E. camaldulensis* stands at Pacca Anna (Pakistan) compared with Girgarre (Australia) could not be attributed to higher potential evaporation in Pakistan.

Greater hydraulic conductivity of the sandy soil in Pakistan (Mahmood *et al*., 2001), or higher rhizospheric conductance into a more extensive root system, also do not account for the observed differences in the vapour pressure deficit at which transpiration is a maximum. While most of climatic and soil factors were comparable at the two study

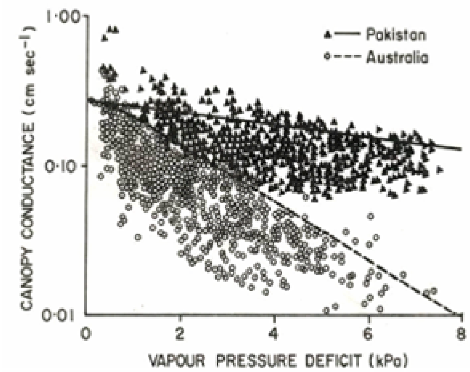

Fig. 5. Relationship between vapour pressure deficit and canopy conductance of *Eucalyptus camaldulensis* trees at Pacca Anna (Pakistan) and Girgarre (Australia).

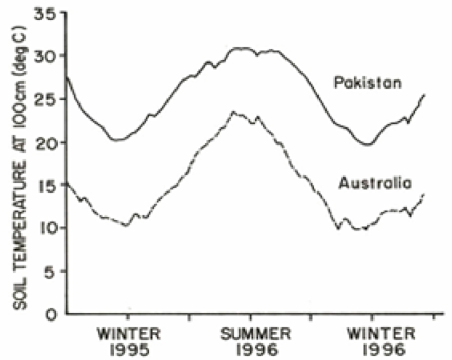

Fig. 6. Soil temperature at 100 cm in rhizosphere of *Eucalyptus camaldulensis* trees at Pacca Anna (Pakistan) and Girgarre (Australia) during the study period.

sites, soil temperature remained markedly lower at Girgarre compared to Pacca Anna throughout the study period (Fig. 6) that might have influenced the root functions. The results imply that the slope of the decline in stomatal conductance with increasing vapour pressure deficit differs between sites, although maximum stomatal conductance is the same. Variations in leaf water efficiency between sites may arise from the influence of environmental factors such as air or soil temperature on stomatal function, possibly mediated by hormonal responses.

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