**PROJECT TITLE**
Relationships amongst water-use efficiency (carbon isotope discrimination) climate and hydraulic architecture of Australian trees

**INVESTIGATOR(S)**

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**INSTITUTION AND DEPARTMENT**

Environmental Sciences, University of Technology Sydney

**SCIENTIFIC OBJECTIVES**

The objectives of this research are to establish:

Whether trees/stands adjust their water use efficiencies (in terms of carbon isotope discrimination) according to climate variation (evaporative demand, rainfall, temperature).

Whether tree/stand water-use-efficiency can be predicted from simple-to-measure leaf traits such as nitrogen content and specific leaf area.

Whether trees/stands adjust their water-use efficiencies according to their ability to supply their leaves with water (i.e. to establish whether water-use-efficiency and hydraulic architecture coordinated?)

**PROGRESS REPORT and RESEARCH OUTCOMES**

(In addition to a discussion of your research results please indicate the value of any other funding generated by AINSE support for this project and the resulting benefits, if any, to the Australian community):

*Leaf-scale predictors of $\delta^{13}C*$

Foliar N concentration and stomatal conductance were found to be unique predictors of $\delta^{13}C$ of the leaf samples. For a given $g_s$, increases in $N_{area}$ were associated with increases in $\delta^{13}C$ (i.e. less negative values of $\delta^{13}C$), while for a given $N_{area}$, increases in $g_s$ were associated with decreases in $\delta^{13}C$ (more negative $\delta^{13}C$) (Figure 1). These relationships also persisted after controlling for variation in SLA, suggesting that the interrelationships amongst $N_{area}$, $g_s$ and $\delta^{13}C$ are not artefacts of their covariance with SLA. Specific leaf area was strongly negatively correlated with $N_{area}$, but was not directly correlated with $\delta^{13}C$.

Mean annual rainfall (MAR) was a significant predictor of $\delta^{13}C$, foliar N concentration per unit leaf area ($N_{area}$) and stomatal conductance (Fig. 2). Site mean $\delta^{13}C$ declined at a rate of 1.0 ‰ for every 400 mm increase in MAR. Stomatal conductance was positively and significantly related to MAR while $N_{area}$ decreased significantly with increasing MAR. Between-site variance in $\delta^{13}C$, $N_{area}$ and $g_s$ was substantially reduced after controlling for variance in rainfall. The inclusion of annual rainfall reduced the between site variance of $\delta^{13}C$, $N_{area}$ and $g_s$ from 12.9% to ≤ 0.01%, 56% to 24%, and from 20.4% to
4.3% respectively. The aridity index (P/E) also explained a substantial portion of the spatial variation in δ¹³C, N_area and g_s. Increased P/E was marginally correlated with reduced δ¹³C (P = 0.07) and significantly correlated with reduced N_area (P = 0.001). Increased P/E was also associated with increased g_s (P = 0.05). Patterns of variation in δ¹³C, g_s and N_area with mean monthly rainfall and mean rainfall of the driest month of the year were similar (in directionality and strength) to the patterns of variation with MAR (Fig. 2). While the site-level variance components for g_s, N_area and δ¹³C were generally smallest after controlling for MAR, overall (suggesting that rainfall accounted for much of the variance in these traits), there was no evidence that any one particular measure of rainfall explained more of the site-level variation in leaf traits than any other. Carbon dioxide assimilation rate, wood density, k_s LA:SA were unrelated to any climate variable(s).

![Figure 1](image-url)

**Figure 1.** A 3-dimensional plot showing relationship between N_area, g_s and δ¹³C. The equation describing the regression plane is: δ¹³C = 1.5(N_area) − 0.45(g_s) − 27.6.
Figure 2 a–h. Relationships between leaf-traits (δ¹³C, gs, N_area and A_area), mean annual rainfall and the aridity index (P/E). Solid lines refer to a significant relationship (P ≤ 0.05), whilst broken lines refer to a marginally significant relationship (P ≤ 0.075). Non-significant relationships are indicated by ns.

Variation in δ¹³C and gs were also correlated to variation in peak daily temperature (P = 0.0005 and 0.03 respectively. Trees of sites with higher peak daily temperatures had higher mean leaf δ¹³C and lower gs. Mean annual temperature and solar radiation were otherwise unrelated to variation in any leaf or branch trait.

At the scale of individual leaves, the best physiological predictors of δ¹³C were gs and N_area (Fig.1). The increase in δ¹³C with increased N_area and decreased gs suggests that leaves with lower gs or higher foliar N concentration were more water-use efficient. Increases in foliar N concentration result in increased water-use-efficiency or δ¹³C because the higher N
concentration of mesophyll cells support a larger photosynthetic rate and this draws down intercellular CO\(_2\) concentration, thereby increasing the CO\(_2\) concentration gradient between the atmosphere and leaf interior. The increased CO\(_2\) concentration gradient results in a larger discrimination against \(^{13}\)C and also a higher assimilation rate for a given rate of water loss (Buckley et al. 2002; Farquhar et al. 2002). The positive relationship between N\(_{\text{area}}\) and \(^{13}\)C observed in the present study is also consistent with a number of previous studies (Macfarlane et al. 2004; Schulze et al. 2006). This finding is important because it shows that variation in \(^{13}\)C is primarily driven by variation in \(g_s\) and N\(_{\text{area}}\), both of which are highly coordinated with measures of site water status (as discussed below).

A discussion of between-site (spatial) variation in leaf and branch traits indicates selection toward increased water-use-efficiency as aridity increases

While much of the leaf-level variation in \(^{13}\)C could be explained by variation in combinations of N\(_{\text{area}}\), \(g_s\), and SLA (SLA largely determines N\(_{\text{area}}\), see Figure 2.2), much of the spatial (site-level) variation in these latter traits could be accounted for by variation in several measures of site rainfall. High (less negative) \(^{13}\)C and N\(_{\text{area}}\) were correlated with low mean annual and mean monthly rainfall, mean rainfall of the driest month, P/E and PC1. Similarly, a high \(g_s\) was correlated with high annual and monthly rainfall, rainfall of the driest month, P/E and PC1 (Fig 2). The concurrent changes in \(^{13}\)C and N\(_{\text{area}}\) with rainfall observed in the present study are qualitatively consistent with the patterns in \(^{13}\)C and N concentration reported by Schulze et al. (1996; 1998; 2006), Miller et al. (2001), Macfarlane et al. (2004) and Wright et al. (2004a; 2005). These relationships are consistent with the theory that species occupying more arid sites possess a suite of adaptations that maximize CO\(_2\) assimilation while simultaneously conserving water (Cowan and Farquhar 1977; Cowan 1982; Meziane and Shipley 2001). Reduced stomatal conductance of trees and species at low rainfall sites minimizes plant water use (or transpiration rate) under conditions of low soil moisture and high evaporative demand, however, the simultaneous increase in N\(_{\text{area}}\) as rainfall declines increases the amount of CO\(_2\) that is fixed for a given \(g_s\) (Fig 1), hence the increase in \(^{13}\)C with decreasing rainfall (Fig 2).

Conclusions arising from this study

This study aimed to identify the key within- and between-site biotic and abiotic factors that drive variation in \(^{13}\)C, CO\(_2\) assimilation and associated leaf and branch traits. Sites experiencing lower mean annual rainfall had higher community mean \(^{13}\)C, suggesting that trees and species of drier sites achieve a more economic use of water. Variation in \(^{13}\)C was itself driven by variation in N\(_{\text{area}}\) and \(g_s\), both of which were highly influenced by rainfall and are likely to underlie the observed relationship between \(^{13}\)C and rainfall. Overall, the interrelationships amongst N\(_{\text{area}}\), \(g_s\), SLA, CO\(_2\) assimilation and \(^{13}\)C suggest a pattern of multiple trait coordination that converge in a way that results in trees and species of drier sites minimising reductions in CO\(_2\) assimilation and maximising water use efficiency. An additional aim of this work was to identify which measure of site water status could best explain variation in community mean leaf and branch traits. While mean annual rainfall (and other similar measures) and minimum leaf water potential explained variation in a few key traits, there was no evidence that any one climate variable was best able to explain variation in leaf and branch traits than any other. Conceptually, this is an unlikely prospect given that variation in leaf- and branch-traits converges in a manner that results in some traits varying independently of site water status.

DATA (Please summarise the data collected within this Award. You may use tables, graphs or diagrams)

Data collected were \(^{13}\)C values for leaf samples taken from a number of sites along an aridity gradient in NSW. (See Figs 1, 2)

Signature of Investigator preparing the report for
After signing this report please fax this page with your signature for our files

Prof DEREK EAMUS, UTS

Proj: AINGRA07043P
Date: 14.5.09
PUBLICATIONS / REPORTS arising as a result of your work.

Please provide references in the following format: Relevant AINSE Grant no(s); paper; Journal, Conference Proceedings or Book Title; Volume, ISSN/ISBN no., or Book/Publisher; Page numbers. Put an (s) to indicate that AINSE support was acknowledged and a (c) to indicate that AINSE has been provided with a copy.

No publications yet that use these data.

PhD STUDENTS For each student involved with the project, please indicate the date or anticipated date of conferment of a PhD or other award, and give the title of the thesis.

The PhD (student: Mr Daniel Taylor) thesis has been examined and the final corrected PhD thesis has been accepted by UTS. The degree will be conferred in late 2009.

Thesis title is: Tree, leaf and branch trait coordination along an aridity gradient.