

Acclimation of whole-plant *Acacia farnesiana* transpiration to carbon dioxide concentration

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Summary Transpiration per unit leaf area of *Acacia farnesiana* (L.) Willd. plants grown at a CO₂ concentration ([CO₂]) of 385 μmol mol⁻¹ was about twice that of plants grown at 980 μmol mol⁻¹. However, when plants grown for more than a year at 980 μmol mol⁻¹ were exposed to 380 μmol mol⁻¹ for 9 days, they transpired at half the rate of those that had been grown at 380 μmol mol⁻¹. Similarly, plants grown at 380 μmol mol⁻¹, when exposed to 980 μmol mol⁻¹, transpired at twice the rate of those grown at 980 μmol mol⁻¹. Thus, the effects of elevated [CO₂] on whole-plant transpiration, like those on photosynthesis, respiration and stomatal conductance, cannot reliably be extrapolated from measurements made during short-term exposure to elevated [CO₂].

Keywords: climate change, CO₂, global change, heat balance, sap flow, stem flow.

Introduction

Atmospheric carbon dioxide concentration ([CO₂]) has risen by approximately 30% since 1750 and is expected to continue rising throughout the 21st century (Houghton et al. 1990). Previous research has shown that short-term exposure to elevated [CO₂] decreases leaf-level transpiration (Kimball and Idso 1983, Goudriaan and Unsworth 1990). However, the way that plants respond to short-term changes in environmental conditions may depend on acclimation to past environmental conditions. Evidence of acclimation to atmospheric [CO₂] has been reported for photosynthesis (Cure et al. 1991, Ceulemans et al. 1997, Osborne et al. 1997, Bryant et al. 1998), respiration (Tjoekler et al. 1999) and stomatal conductance (Xu et al. 1994, Chen et al. 1995, Santrucek and Sage 1996, Polley et al. 1997), but not, so far as we are aware, for whole-plant transpiration.

In this study, we examined acclimation of whole-plant transpiration to [CO₂] in the woody legume *Acacia farnesiana* (L.) Willd., a species that occurs widely in the south-central USA (Van Auken and Bush 1985) and is among the most aggressive woody plant invaders of grasslands worldwide (Polley et al. 1997).

Materials and methods

Polley et al. (1997) provided a detailed description of the present study. Briefly, sap flow measurements of whole-plant transpiration were made in August and September 1993 on *A. farnesiana* plants grown from seed sown in August 1992 in three air-conditioned greenhouse bays in Temple, TX.

Growth conditions

Beginning in August 1992, greenhouse bays were maintained continuously at CO₂ concentrations of 385, 690 or 980 μmol mol⁻¹. Nine *A. farnesiana* plants were grown in each bay ($n = 27$). Three plants were grown in each of three 0.65 × 0.65 × 0.9-m (380 l) pots containing a fine, thermic Udic Paleustalfs (Pedernales fine sandy loam). The plants were well watered. Temperatures and water vapor pressures were similar in the three greenhouses.

Photosynthetic photon flux density (Q_p) was measured near the top of each bay.

Plant analysis

Aboveground portions of all *A. farnesiana* plants were harvested in October 1993 (Polley et al. 1997). At harvest, total, one-sided leaf area of each plant was calculated as the product of leaf mass per plant and specific leaf area. Mean (\pm standard deviation) leaf areas of plants equipped with sap flow gauges in the 385, 690 and 990 μmol mol⁻¹ CO₂ treatments were 1.95 \pm 0.057, 1.93 \pm 0.53 and 3.28 \pm 1.91 m² plant⁻¹, respectively.

Transpiration measurements

Daily whole-plant transpiration of three *A. farnesiana* plants per [CO₂] ($n = 9$) was measured with constant-power sap flow gauges (Baker and van Bavel 1987) from August 26 (Day 238) to September 18 (Day 261), 1993. Daily transpiration totals were calculated from 15-min transpiration means. Gauge installation and data analyses followed that of Dugas et al. (1993).

Validation of sap flow estimates of whole-plant transpiration

Transpiration of a single potted plant of *A. farnesiana* was measured gravimetrically and, simultaneously, with a sap flow gauge to yield similar values of 365 and 374 g day⁻¹, respectively, during a period in which daily transpiration ranged from < 50 to nearly 600 g day⁻¹.

Validation of leaf area normalization

The validity of leaf area normalization was confirmed by regression of transpiration per unit leaf area, measured in plants at their growth [CO₂] on days when irradiance was above a threshold, versus whole plant leaf area, which yielded a linear correlation coefficient not significantly different from zero ($P < 0.05$).

Measuring short-term responses to changed [CO₂]

To examine the effect of short-term changes in [CO₂] on whole-plant transpiration, the [CO₂] in each greenhouse bay was changed at about 0600 h on Days 242 through 251 (August 30–September 9, 1993). In the bay with a 385 μmol mol⁻¹ growth [CO₂], the [CO₂] was raised to 690 μmol mol⁻¹ on Days 242 and 245 and to 980 μmol mol⁻¹ on Days 243, 246, 247, 250 and 251. In the bay with a 690 μmol mol⁻¹ growth [CO₂], the [CO₂] was lowered to 385 μmol mol⁻¹ on Days 243, 246, 247 and 251 and raised to 980 μmol mol⁻¹ on Days 242 and 245. In the bay with a 980 μmol mol⁻¹ growth [CO₂], the [CO₂] was lowered to 385 μmol mol⁻¹ on Days 242, 245 and 250 and to 690 μmol mol⁻¹ on Days 243, 246, 247 and 251.

Statistical evaluation of data

The effect of [CO₂] on transpiration was examined based on the ratio of daily transpiration per unit leaf area, T (g m⁻² day⁻¹) to daily mean Q_p (μmol m⁻² s⁻¹). Treatment effects on T/Q_p , which adjusted for leaf area differences between plants and for radiation differences between days, were evaluated by ANOVA, with [CO₂] as the main effect and plants as replicates.

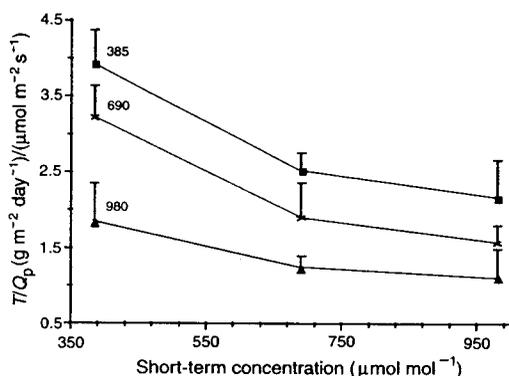


Figure 1. Ratio of mean daily total transpiration (T) per unit leaf area (one-sided) of *Acacia farnesiana* to mean daily photosynthetic photon flux density (Q_p) as a function of short-term carbon dioxide concentration ([CO₂]) at which plants were measured. Lines represent growth [CO₂] and vertical bars represent sample standard deviation.

Results and discussion

The mean of the ratio of total daily transpiration per unit leaf area to mean daily irradiance (T/Q_p) decreased when the short-term [CO₂] increased (Figure 1). For each growth [CO₂], there was a consistent decrease in T/Q_p when the short-term [CO₂] increased from 385 to 690 μmol mol⁻¹ (37%) and from 690 to 980 μmol mol⁻¹ (15%). At each short-term [CO₂], T/Q_p was about twofold greater in plants grown at 385 μmol mol⁻¹ than in plants grown at 980 μmol mol⁻¹. These results demonstrate that plants grown for more than a year at a [CO₂] of 980 μmol mol⁻¹ had acclimated to the elevated [CO₂] in a way that reduced transpiration at a given [CO₂] compared with transpiration in plants grown at a lower [CO₂]. To our knowledge, these are the first results to show acclimation of whole-plant transpiration to [CO₂] and are consistent with acclimation of stomatal conductance of *A. farnesiana* shown by Polley et al. (1997).

In each short-term [CO₂] treatment, transpiration of plants grown at 690 or 980 μmol mol⁻¹ was less, at a given Q_p , than that of plants grown at 385 μmol mol⁻¹ (Figure 2). For example, in the short-term 385 μmol mol⁻¹ CO₂ treatment, plants acclimated to 980 μmol mol⁻¹ transpired at only half the rate of plants acclimated to 385 μmol mol⁻¹, and transpiration of plants acclimated to 690 μmol mol⁻¹ was about 80% that of plants acclimated to 385 μmol mol⁻¹ (Figure 2, top panel). Similarly, in the short-term 980 μmol mol⁻¹ CO₂ treatment, plants acclimated to 385 μmol mol⁻¹ had about twice the tran-

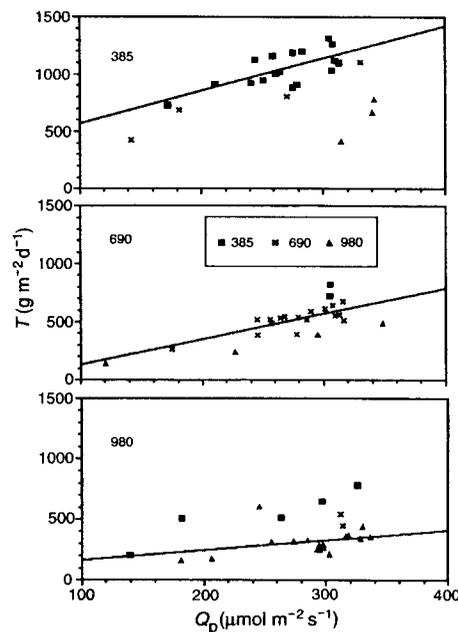


Figure 2. Total daily transpiration (T) per unit leaf area (one-sided) of *Acacia farnesiana* plants measured at short-term carbon dioxide concentrations ([CO₂]) of 385 (top panel), 690 (middle panel), and 980 (bottom panel) μmol mol⁻¹ as a function of mean daily photosynthetic photon flux density (Q_p). Symbols indicate growth [CO₂]. Lines are linear regressions through measurements taken at each growth [CO₂].

spiration, at a given Q_p , of plants acclimated to 980 $\mu\text{mol mol}^{-1}$ (Figure 2, bottom panel).

On days when the growth $[\text{CO}_2]$ and the short-term $[\text{CO}_2]$ were the same, the slope of the relationship between transpiration and Q_p was 2.85, 2.20 and 1.33 for the 385, 690 and 980 $\mu\text{mol mol}^{-1}$ CO_2 treatments, respectively ($P < 0.128$) (Figure 2). Jones et al. (1985) showed a similar effect of $[\text{CO}_2]$ on the $T-Q_p$ relationship.

In summary, long-term exposure to elevated $[\text{CO}_2]$ reduced water use per unit leaf area. The reduction was greater than would be predicted from the transpiration of plants subjected to short-term exposure to elevated $[\text{CO}_2]$. We conclude that the effect of long-term exposure to elevated $[\text{CO}_2]$ on transpiration, like that on photosynthesis, cannot be directly extrapolated from the effect of short-term exposure to elevated $[\text{CO}_2]$.

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