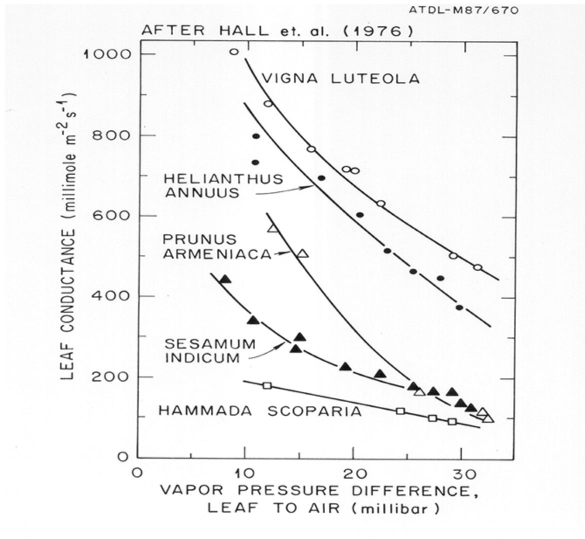
Stomatal Conductance, part 2

- Environmental Biology, Continued
  - Response of stomata to environmental and physiological forcings
    - humidity deficits
    - temperature
  - relation to hydraulic conductance
  - tree age/height.
  - soil moisture
- Diurnal variations of stomata
  - ample soil moisture
  - soil moisture deficits
- Dynamic Responses

Stomatal conductance has a strong dependence upon humidity deficits

Stomatal Conductance and Humidity Deficits, Data



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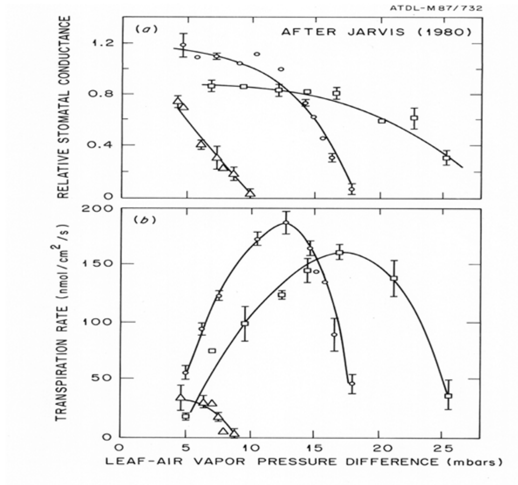
There is no universal function between stomatal conductance and humidity deficits. Some plants are more sensitive than others

Hall et al 1976.

Stomatal Conductance and Humidity Deficits, Data



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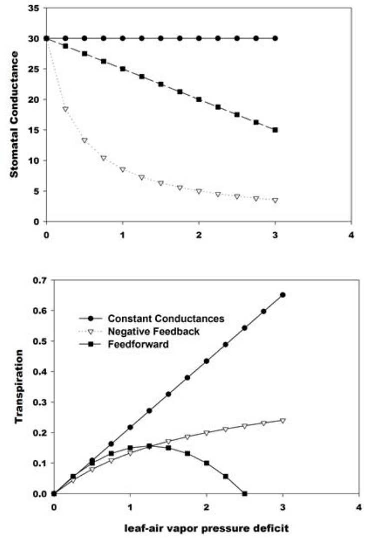
Other data show complex interactions between humidity deficits, transpiration and stomatal conductance…leading others to consider feedback and feedforward response.

Which Behavior Does the Previous Data Support?

Feedforward

$$g_l = e - f\Delta e_l$$

$$E = e\Delta e_l - f(\Delta e_l)^2$$



Feedback

$$E = g_s(\Delta e_l)\cdot \Delta e_l$$

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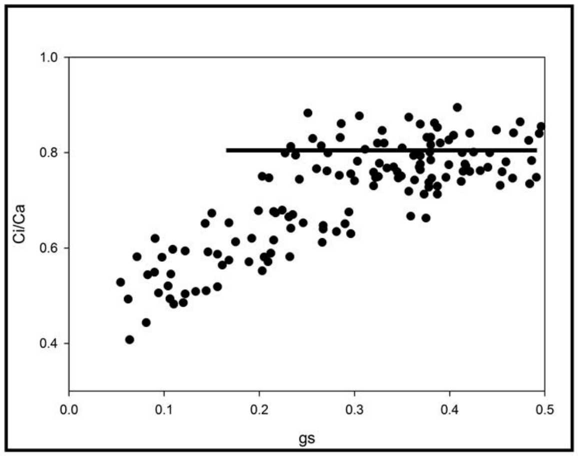
Farquhar and Jones are among those arguing in terms of feedforward rather than feedback effects on stomata, humidity and transpiration.

Wikipedia

Feed-forward is a term describing an element or pathway within a control system which passes a controlling signal from a source in its external environment, often a command signal from an external operator, to a load elsewhere in its external environment. A control system which has only feed-forward behavior responds to its control signal in a pre-defined way without responding to how the load reacts; it is in contrast with a system that also has feedback, which adjusts the output to take account of how it affects the load, and how the load itself may vary unpredictably; the load is considered to belong to the external environment of the system.

Ci/Ca and Stomatal Conductance



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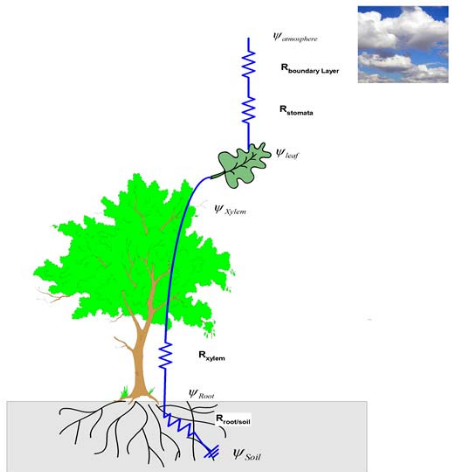
Lots of data show that happy leaves have a operating point where stomata open and close to keep the ratio of the internal CO2 concentration to its atmospheric value near 0.7 (for C3 leaves). Our data supports this for as long as the stomata are relatively open. Closure can cause a drawdown in Ci and reduce this ratio. Isotopic ecohydrologists use measures of the stable isotope content of a leaf, del 13C as a measure of ci/ca and infer stomatal conductance.



$$E = g_s \Delta e = k_l (\Psi_{soil} - \Psi_{leaf})$$

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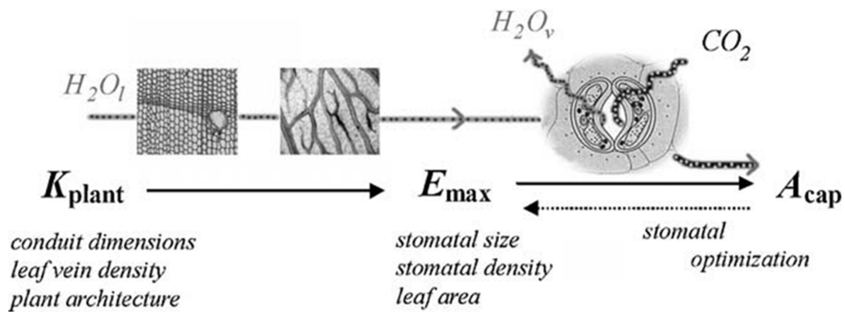
Stomata are coupled to leaves, coupled to xylem, coupled to roots and the soil. So we need to consider the soil-plant-water-atmosphere continuum to understand stomatal behavior during periods of soil moisture deficits.

Links between Plant Hydraulics and Conductance



Brodribb 2009 Plant Science

Hydraulic Conductance Modulates Stomatal Conductance

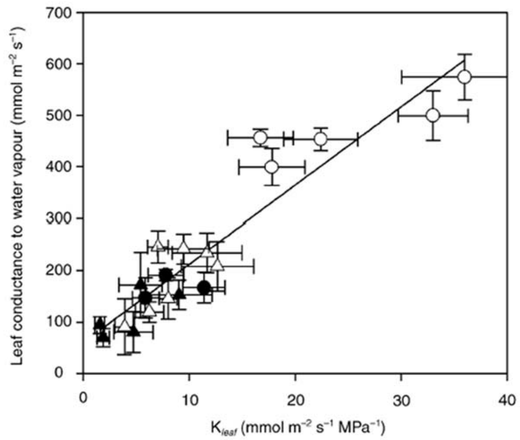


Fig. 2 A highly significant linear correlation ($r^2 = 0.87$) between mean leaf hydraulic conductance (± SD; $n = 9$) and stomatal conductance (± SD; $n = 9$) in a sample of tropical (○) and temperate (△) angiosperms, tropical ferns (●), and temperate conifers (▲).

Brodribb et al New Phytol 2005

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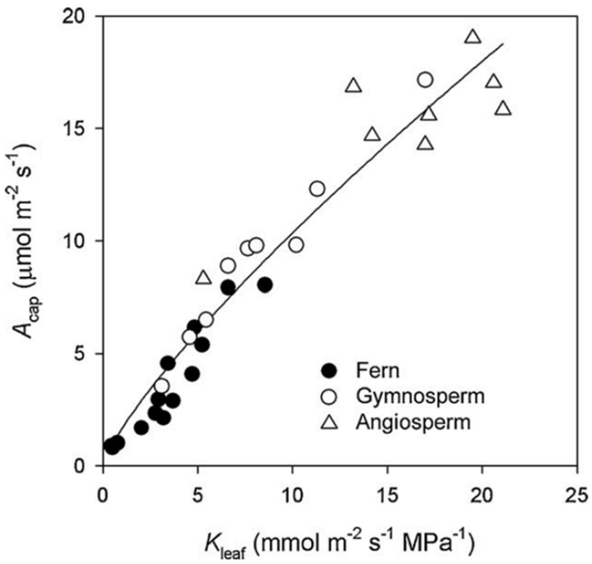
There is a tight linkage between the hydraulic plumbing of a plant and stomatal conductance



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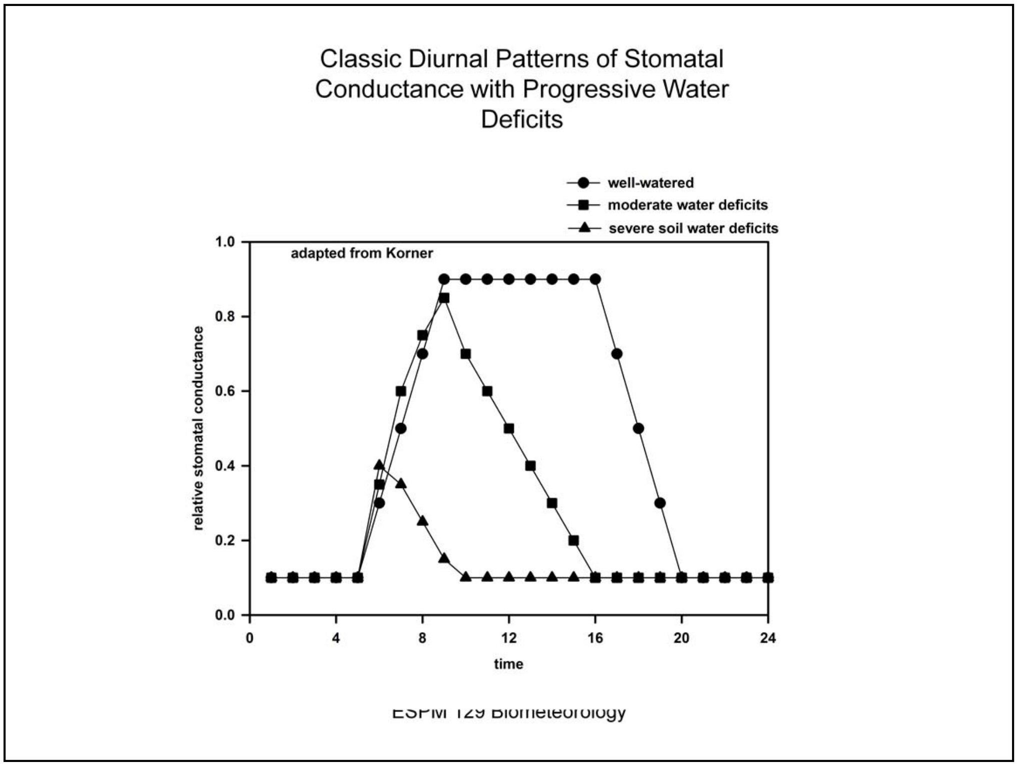
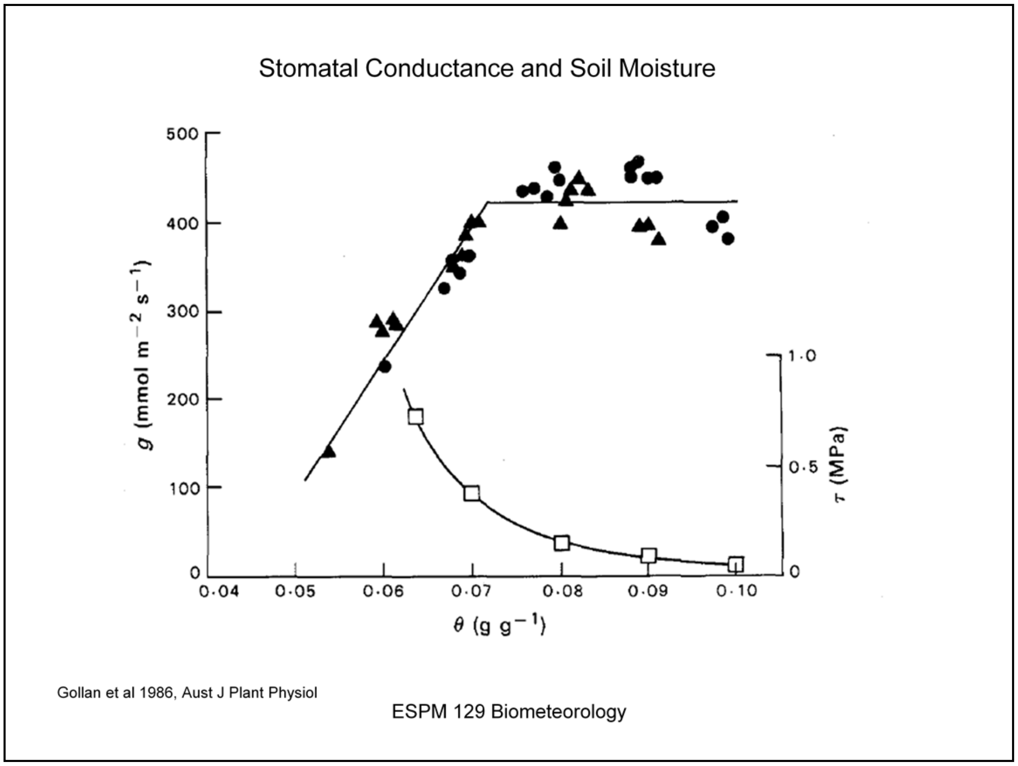
Also a link between conductance and photosynthesis

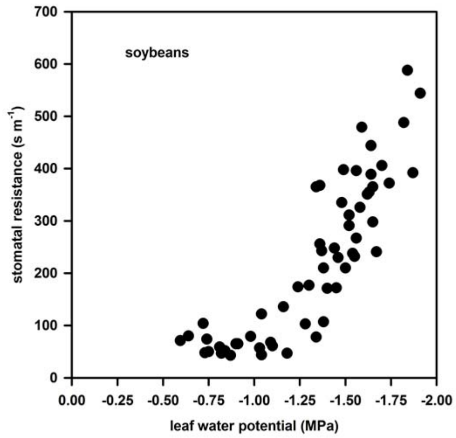


Soil water deficits have an impact on the value and diel course of stomatal conductance.



Stomata close with less water in soil. But plants are better measures of the energy that water is held, eg water potential, than moisture content. Available water can differ greatly for sand, clay and loam for the same water content in the soil.

Stomatal Resistance and PreDawn Water Potential: soybeans



Baldocchi, dissertation, 1982

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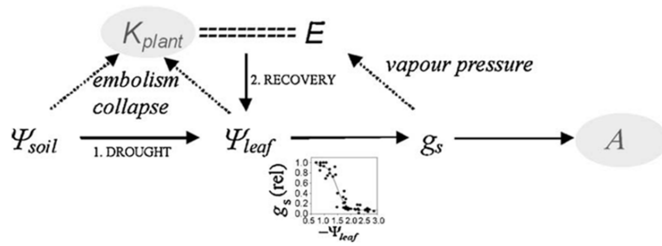
Lots of data, including some from my dissertation, show that stomata stay open until a critical water potential, lik -1.0 to -1.5 Mpa. Then they close, increasing the resistance, or decreasing the conductance.

Drought, Embolism and Stomatal Closure



Brodribb 2009 Plant Science

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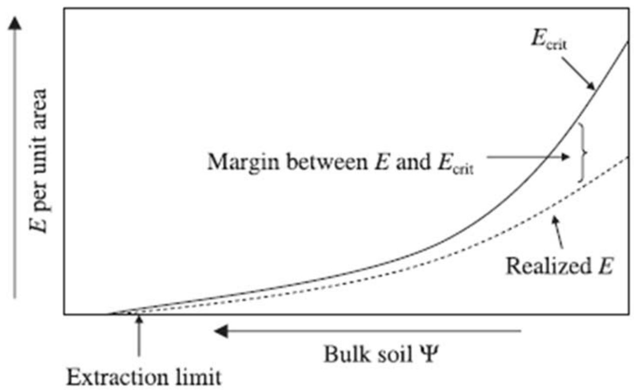
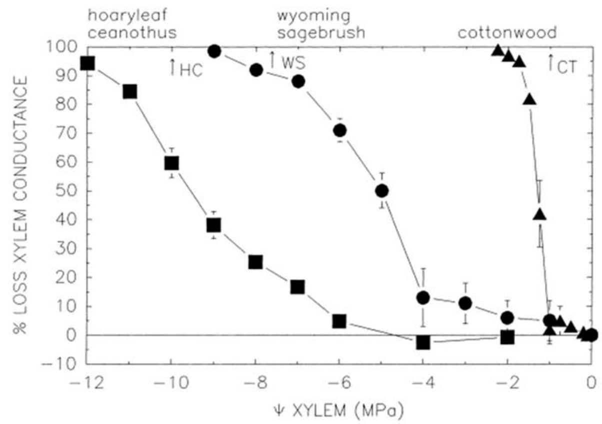
Trees don’t like to have bubbles or embolisms form in their xylem. So as soils dry there can be feedbacks to reduce the hydraulic conductance

Hydraulic Failure Occurs if Plants are Forced to Achieve Transpiration rates, E, greater than the Critical Value

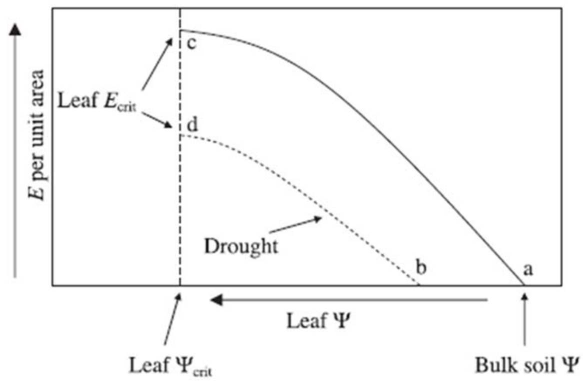


Stomata Operate to Conserve Water and Prevent Cavitation,
Loss of Xylem Conductance;
Plants Acclimate/Evolve Differently to Drought Severity

J.S. Sperry / Agricultural and Forest Meteorology 104 (2000) 13–23



Coordinated Changes in Soil-Plant-Water Continuum with Drought



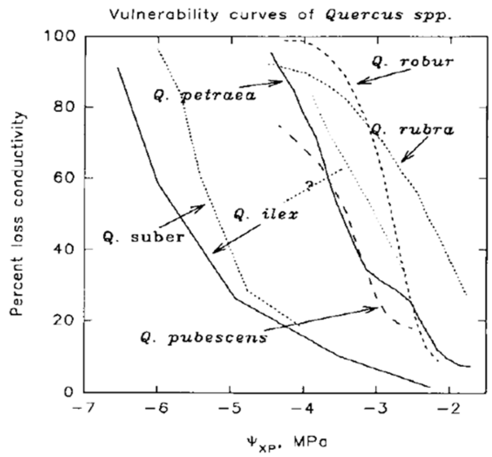
Mild Deficits: Stomata Operate to prevent Cavitation and Control Transpiration

Moderate Deficits: Cavitation Occurs, Xylem Conductance is Lost; peak Transpiration Declines

Severe Deficits: Hydraulic Failure; Mortality

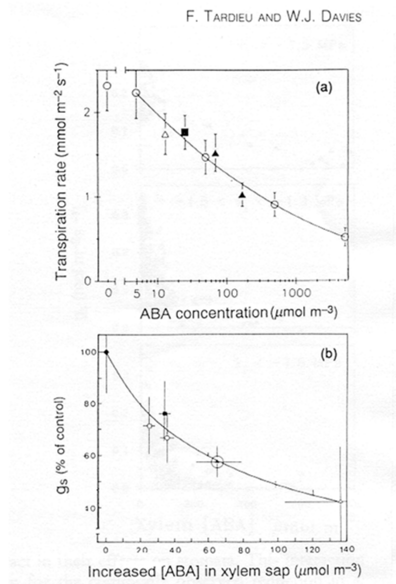
McDowell et al 2008 New Phytologist

Which Oaks are Adapted to the More Severe Water Deficits?



Tyree and Cochard, 1996

Evidence of ABA Hormone Controlling Stomata and Transpiration Under Water Deficits



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response phases of gs to vpd

- low vpd, E is limited by vpd and not gs. As vpd increases, E increases so stomatal conductance does not limit transpiration
- at mid range values of VPD, stomata close as VPD increases. E remains constant as the increase in the driving force is equal to the change in conductance
- At high VPD, feedforward effects are noted, causing E to decline as V increases more. Hydraulic limitations limit the supply of water

Summary, Key Points

- From an environmental standpoint, stomata open and close with changes in light, temperature, humidity, CO_2, soil moisture, a hormone (ABA) and transpiration. Stomatal conductance scales with photosynthesis and transpiration. As guard cells respond to light, their solute concentration increases. This allows water to enter the guard cell, forcing them to bow and open.
- As guard cells respond to CO_2, there is a solute efflux from the guard cells. This forces the turgor of the guard cells to decrease and the stomata to close.
- Direct effects on stomata occur by high transpiration rates and high humidity deficits. Water loss from the guard cells force them to close.
- Soil moisture deficits trigger the product of ABA, which acts as a signal and causes stomata to close.
- Stomata tend to open and close to maintain C_i/C_a of C3 plants near 0.7 and C_i/C_a of C4 plants near 0.4.
- From a dynamic standpoint, stomatal movement is relatively slow, changing over the course of a half-hour to a change in light. The time response will be faster if a leaf is induced.
- The shape of the diurnal pattern of stomatal conductance is a strong indicator as to whether the plant is suffering from soil water deficits.
- When soil moisture deficits occur, stomatal closure can be patchy.