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Is optimality in stomatal conductance an endogenous process or an emergent property arising from interactions with the environment?

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Plants are sessile and poikilothermic organisms that need to respond and adjust promptly to an ever-changing environment. Over a single 24 h period, a plant may experience the same level of variation in radiation as in its entire life-time and, in some climates, the oscillation in day-night temperature and vapor pressure deficit might be of similar magnitude to that experienced across a full year. Plants need to maintain a positive C balance without depleting soil water reserves in the face of such a diverse environment, and feedbacks between assimilation (A) and water losses (E) are thought to have evolved to optimize stomatal conductance (g_s). In short, the optimal conductance hypothesis proposes that cross-talks between A and stomatal conductance g_s lead to a constant marginal water use (λ) during a day, such that A is maximized and E minimized. The biological mechanism by which biochemical processes would feedback g_s remains unknown, but multiple studies have shown empirical support for this hypothesis, leading to its current consideration of theory by many.

Here we test whether optimal stomatal conductance is an endogenous property, that is, driven solely by factors internal to the plant, and in the absence of environmental fluctuations. After 5 days of entrainment, where monoculture canopies of bean and of cotton were subjected to the average environmental conditions of an August sunny day in Montpellier (at the CNRS European Ecotron, FR), we kept temperature, relative humidity and photosynthetically active radiation constant for 48 h at the values observed at noon. During this period, we monitored leaf gas exchange continuously every two minutes, and canopy gas exchange every 15 minutes. We observed a periodic oscillation in λ, showing a 24 h period, and consistent with a circadian regulation of water use efficiency. Hourly variations in λ could thus not be explained by the optimal stomatal hypothesis. Moreover, the pattern of variation (of maximal water use efficiency during the “subjective” night hours, and minimal during the subjective daytime) indicate that endogenous plant processes tend towards "wasting"’ water for maximizing A, instead of optimizing water use. We thus conclude that optimal stomatal conductance, at least in the species studied, is an emergent property resulting from interactions with environmental cues. Models based on optimality theory are currently widespread within the Earth System sciences, and our results shed new light into its mechanistic basis.