Physiological tradeoffs of stomatal closure under high evaporative gradients in field grown soybean (*Glycine max*)

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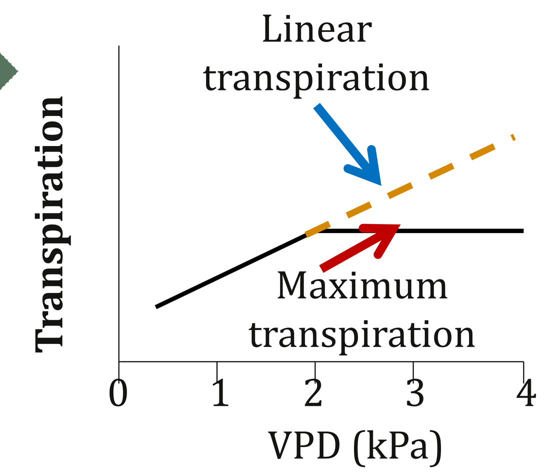
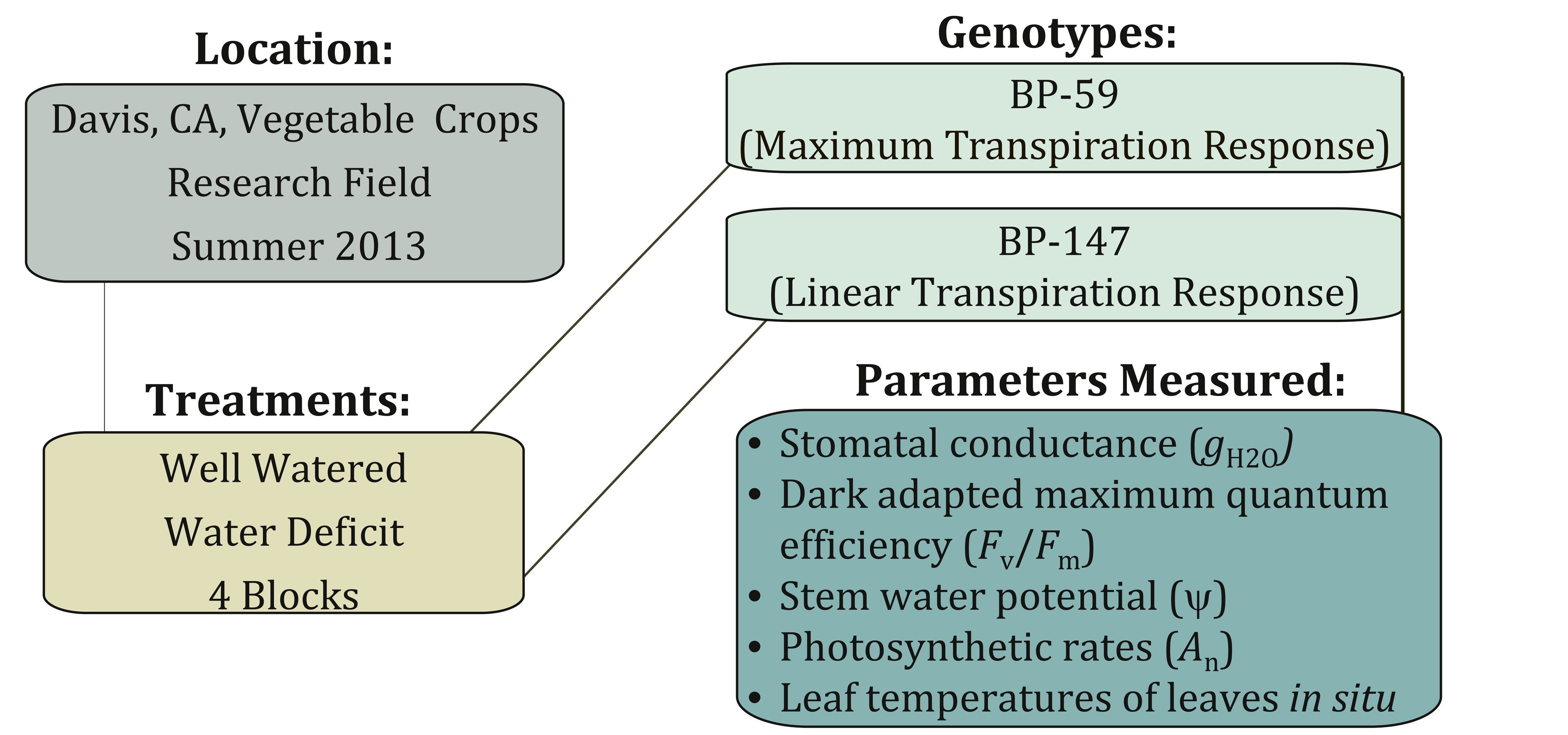
Abstract



Limited rainfall is the main constraint to agriculture. Thus, agricultural research that aims to understand plant behavior leading to soil water deficit avoidance is a matter of priority. One emphasis has been screening for varieties that decrease stomatal conductance (g_{H2O}) under high vapor pressure deficit (VPD), a proxy for leaf evaporative gradient.

However, the link between g_{H2O} closure and physiological consequences in the field is not yet clear. When ambient temperatures exceed optimum leaf temperatures (T_{leaf}), maintaining high g_{H2O} and transpiration rate results in evaporative cooling of leaves. Particularly under soil water deficit, water conservative crops are at risk of photosynthetic (A_n) heat stress from decreased evaporative. The aim od this study is to identify T_{leaf} thresholds that result in A_n damage and compare them to the range present in soybeans bred for maximum transpiration responses and grown in the field.

Methods and Materials



Hypothesis

Stomatal closure under high evaporative demand conditions leads to **above optimum leaf temperatures** for photosynthesis and thus will lead to ***photosynthetic damage.***

Results

Atmospheric effects on the g_{H2O} to evaporative gradient relationship

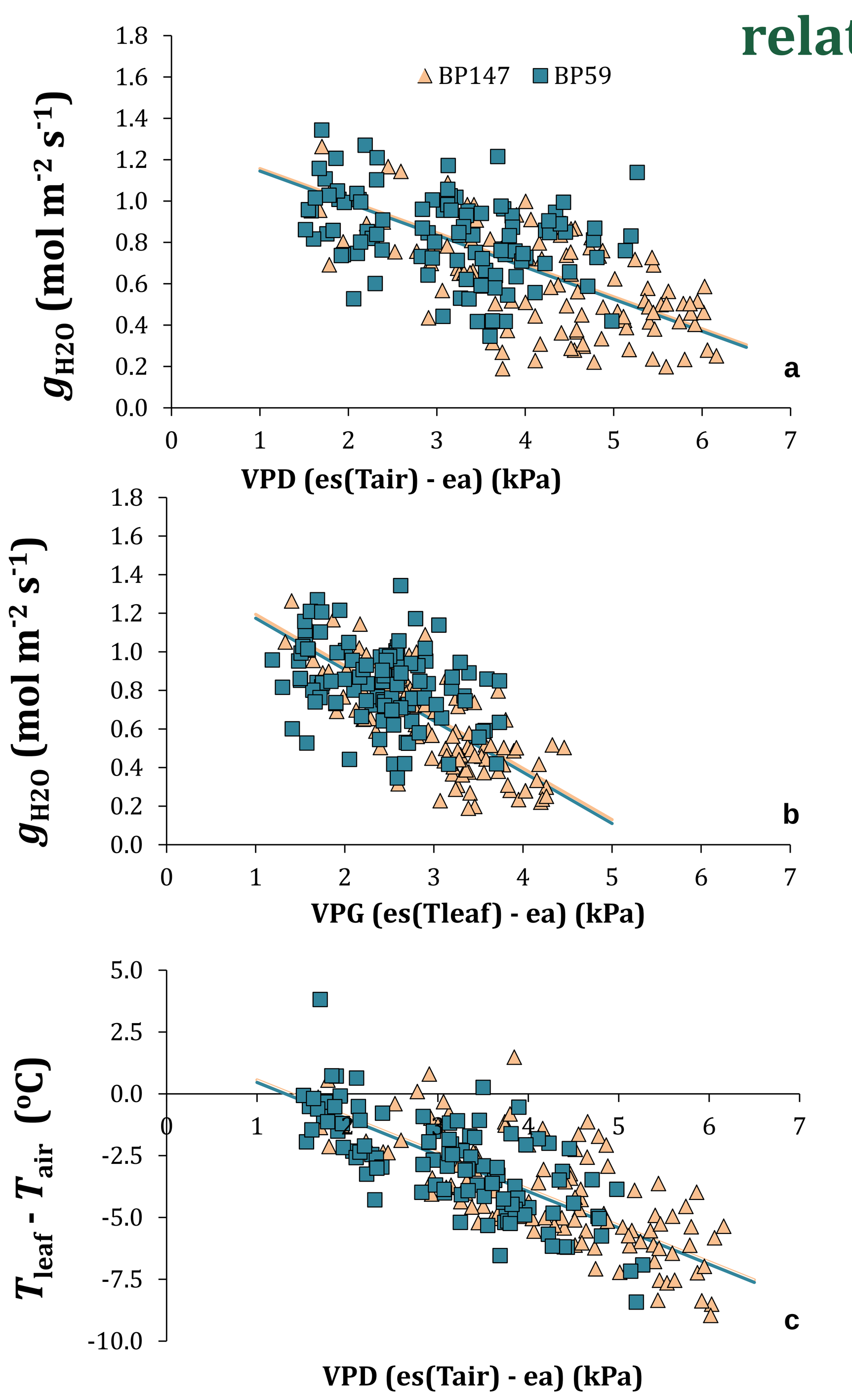


Fig 1. Data were analyzed using both VPD (Fig.1a), and VPG (Fig.1b). Both of these evaporative gradients had significant (p<0.001) relationships with g_{H2O}. Unlike expected, no significant differences were found between genotype stomatal response to VPD or VPG (p>0.51). The inclusion of T_{leaf} in the evaporative gradient brought all points to a much smaller range of VPG. The large decrease in VPG relative to VPD was proportional to T_{leaf} being ~7.5°C lower than T_{air} at high VPD, while no difference was apparent at ~1.5kPa VPD (Fig.1c).

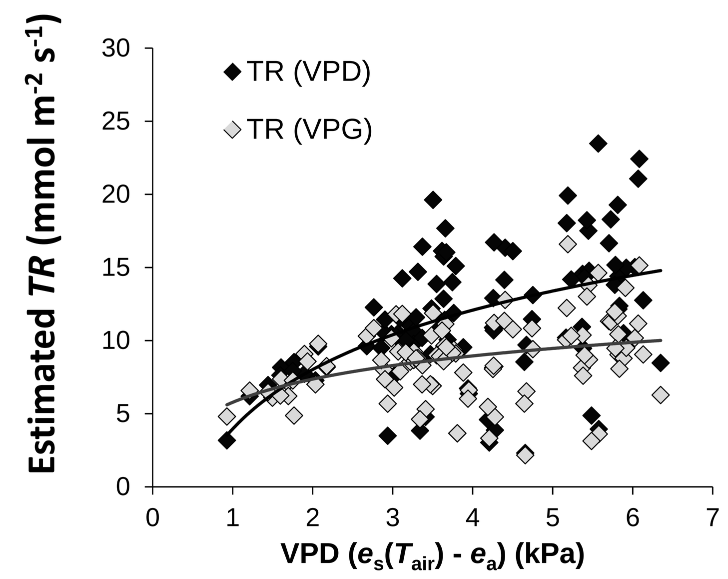


Fig. 2: The evaporative cooling of leaves relative to air temperature at high VPD affected transpiration rates (TR) as VPD overestimated the evaporative gradient. The approximate magnitude of this effect was explored by estimating transpiration using a flux equation (eqn.1). For a leaf exposed to the wind speed measured at 2m height, TR was estimated to drop by on average 38% when evaporative cooling was accounted.

eqn. 1:

$$TR = \left(\frac{1}{g_{H20}} + \frac{1}{g_{blc}}\right)^{-1} \frac{[e_s(T_{leaf} \text{ or } T_{air}) - e_a(T_{air}, RH)] * 1000}{P_{atm}}$$

Combined effects of high T_{leaf} and stomatal closure on A_n

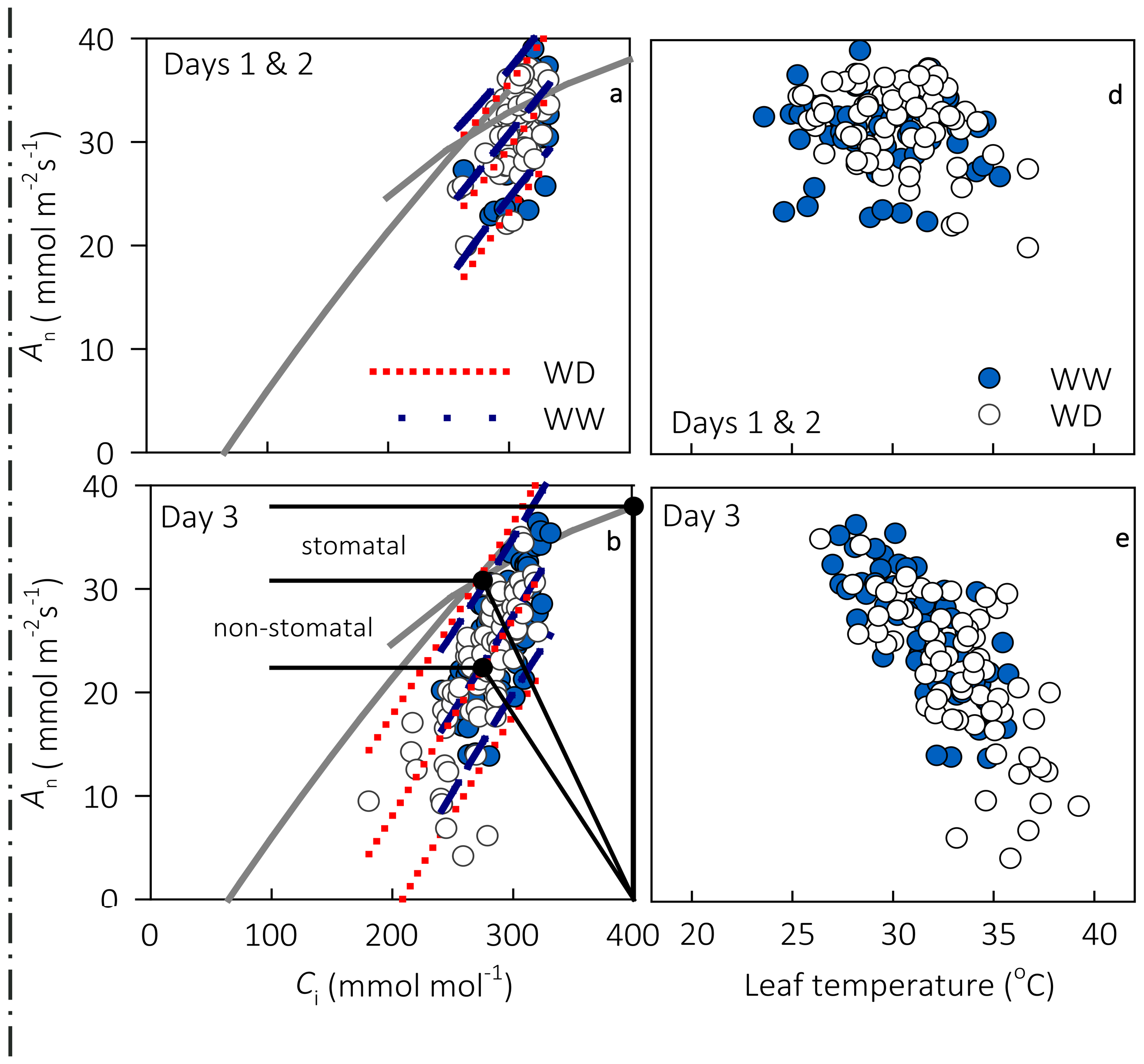


Fig. 3. Photosynthesis spot measurements made over the course of three days (points) with illustrative CO_2 response (curves measured at T_{leaf} 32.9°C) (panels a-b), and the same spot measurement data relative to leaf temperature (panels d-e).

Net A_n rates decreased at high T_{leaf} for both irrigation treatments (Fig.4d-e). The largest decrease in A_n occurred on the day of highest temperatures and VPG (Fig.4b). Thus decreases in A_n appeared to be primarily related to considerable increases in VPG, resulting in stomatal limitations to A_n associated with decreases in C_i, and secondarily to soil water deficit (Fig.4a-b).

The day with highest evaporative demand (Day3), and to a lesser degree the other days, had large decreases in A_n due to non-stomatal limitations as evidenced by the prediction intervals for points at low C_i being below CO_2 response curves of typical unstressed soybeans (Fig.4a-b).

Temperature Responses

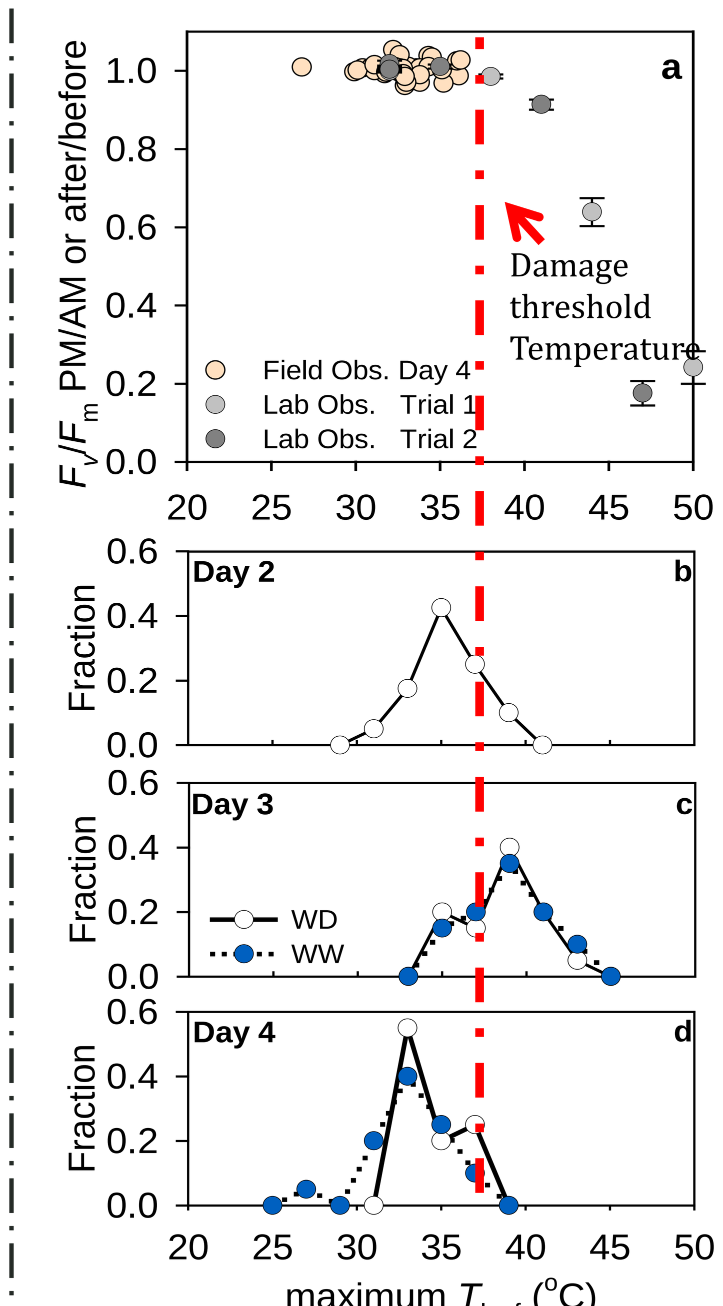


Fig.4. Laboratory temperature response curves of F_v/F_m revealed a temperature threshold for damage or photoinhibition to PSII at about 38°C (Fig.4a).

For the field, the majority of leaves monitored over the course of the hottest day (Day3), reached 38°C or higher at some point in the day, regardless of irrigation treatment (Fig.4c). However, F_v/F_m measurements, an indication of slowly reversible NPQ and photoinhibition, did not show a decrease by three hours past sunset. This indicates a total and rapid recovery of NPQ, or lack of photoinhibition.

Discussion

Stomatal closure under high evaporative resulted in higher leaf temperatures (Fig.4d-e), and thus VPD poorly predicted the driving force for transpiration, the *vapor pressure gradient* (Fig.2). Considerable non-stomatal limitations to A_n occurred in leaves exposed to high evaporative conditions, when leaf temperature is high and is coupled with stomatal closure. The latter behavior has been suggested as a mechanism for increasing crop water conservation and drought resistance. While this selection strategy does appear to have negative consequences, leaves demonstrated a capacity for repair or recovery from the effects of combined stomatal limitations and heat stress in the moderate-high temperatures tested here. The response of g_{H2O} to evaporative gradient during soil water deficit had unexpected sensitivity under the least stressful daily conditions. Therefore, more evaluation of the field performance of the physiology of water conservative genotypes under high temperatures and soil water deficit is needed.

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