Stomatal and non-stomatal limitations to carbon assimilation in response to rainfall pulses in woody plant seedlings

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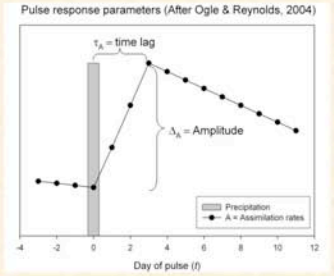
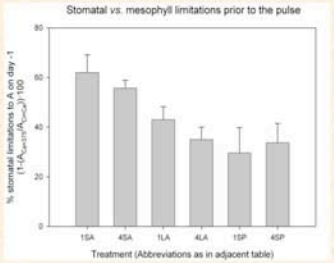
Overview

Seedlings of the C3 warm-desert shrub *Prosopis velutina* are highly dependent on summer rainfall pulses for growth and survival. The magnitude of the increase in physiological activity in response to pulses (Δ) has been hypothesized to depend on 1) plant water stress prior to the pulse ($\Psi_{t=-1}$); 2) the intensity of the pulse (R) and 3) τ_y, the time lag in the upregulation of y, the physiological process of interest (modified from Ogle & Reynolds 2004). The effects of R on Ψ_t are likely to be controlled by soil texture and rooting distribution (older seedings will be relatively more decoupled from pulses than younger seedlings if they can tap deeper water sources). We evaluated Δ_A (Δ of leaf-level assimilation) in response to a 39mm rainfall pulse on highly contrasting sandy loam and loamy clay soils after two months of drought and also during the peak of the summer rainy season (only on the sandy loam soil) in southeastern Arizona, USA. The role of seedling age and its relation to rooting distribution was evaluated by comparing the gas exchange characteristics of one and four year-old seedlings. We evaluated stomatal and mesophyll limitations to photosynthesis to understand processes affecting responses to the pulse. Where moisture duration is shorter (sandy loam surface), *P. velutina* seedlings are poised to take advantage of pulses by having biochemistry in a 'ready' state. This likely comes at a cost, and with higher potential of soil residual water from previous pulses (loamy clay surface), plants need to upregulate their biochemical capacity, which results in longer τ_A and smaller Δ_A. Younger seedlings showed higher Δ_A, probably associated with their shallower active root profile.





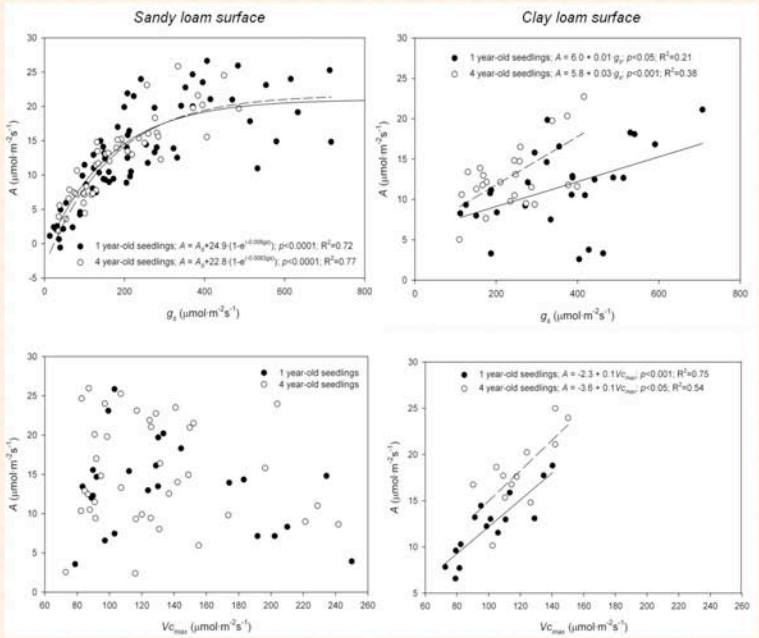
Response of Assimilation and Ψ to a 39mm Pulse as a Function of Antecedent Conditions

Treatment	Ψ (Mpa)	τ_A (days)	A (μmol m^{-2} s^{-1})
(1SA) 1 year-old	$\Psi_{t=-1}$ = -3.4 (1.6)		$A_{t=-1}$ = 3.7 (3.6)
Sandy loam	$\Psi_{t=7}$ = -1.5 (0.5)	3	$A_{t=b}$ = 22.1 (2.0)
After drought	Δ_Ψ = 2.9		Δ_A = 18.3
(4SA) 4 year-old	$\Psi_{t=-1}$ = -4.7 (0.1)		$A_{t=-1}$ = 6.5 (4.7)
Sandy loam	$\Psi_{t=7}$ = -1.5 (0.1)	4	$A_{t=b}$ = 10.4 (3.9)
After drought	Δ_Ψ = 3.2		Δ_A = 3.8
(1LA) 1 year-old	$\Psi_{t=-1}$ = -2.7 (1.2)		$A_{t=-1}$ = 9.5 (1.4)
Loamy clay	$\Psi_{t=7}$ = -1.3 (0.1)	5	$A_{t=b}$ = 14.7 (4.8)
After drought	Δ_Ψ = 1.4		Δ_A = 5.2
(4LA) 4 year-old	$\Psi_{t=-1}$ = -2.7 (1.1)		$A_{t=-1}$ =12.4 (0.8)
Loamy clay	$\Psi_{t=7}$ = -1.5 (0.2)	4	$A_{t=b}$ = 13.8 (4.9)
After drought	Δ_Ψ = 1.2		Δ_A = N.S.
(1SP) 1 year-old	$\Psi_{t=-1}$ = -1.1 (0.4)		$A_{t=-1}$ =18.2 (6.6)
Sandy loam	$\Psi_{t=7}$ = -0.8 (0.5)	1	$A_{t=b}$ = 19.1 (4.7)
Peak-monsoon	Δ_Ψ = N.S.		Δ_A = N.S.
(4SP) 4 year-old	$\Psi_{t=-1}$ =-1.4 (0.4)		$A_{t=-1}$ = 15.3 (3.9)
Sandy loam	$\Psi_{t=7}$ = -1.0 (0.2)	4	$A_{t=b}$ = 19.4 (4.3)
Peak-monsoon	Δ_Ψ = N.S.		Δ_A = N.S.

Antecedent Drought Impacts on Photosynthesis Limitations of Different Seedling Cohorts in Response to Pulses

- The magnitude of the response to the pulse is inversely correlated with water stress on day –1.
- Highest control of stomatal limitations on A on sandy loam seedlings after drought (ca. 60%), followed by loamy clay seedings after drought (ca. 40%).
- Percent of stomatal limitations is inversely correlated with Ψ on day –1.
- 4 year-old seedlings show less response to the pulse than 1 year-old seedlings.

What Drives the Differences in Pulse Responses Across Soil Texture and Seedling Age?



Phenotypic Trade-offs in Stomatal *vs.* Non-Stomatal Reponses to Pulses Mediated by Soil Texture

Sandy loam surface:

- High stomatal limitations to assimilation
- No downregulation of carboxylation capacity in response to drought
- *Prosopis* seedlings to avoid critical cavitation thresholds while sustaining photosynthetic function in a 'ready' state to take advantage of intermittent moisture availability
- Low response times to the pulse and high increases in physiological activity

Loamy clay surface:

- Lower stomatal limitations to assimilation.
- Downregulation of carboxylation capacity in reponse to drought
- Lower intermittency in moisture availability diminishes risk of catastrophic xylem failure resulting in smaller investment in carboxylation efficiency during drought and higher stomatal conductance
- High time to respond to the pulse and low increases in physiological activity.

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Reference:
Ogle, K. and J.F. Reynolds. Oecologia, 2004. **141**(2): p. 282-294