A matric-flux potential expression to predict limiting hydraulic conditions for root water uptake

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Introduction and objective

Hydraulic properties determine the ability of soils to supply water to plants. The ability of a soil to provide transpirable water to plants under dry conditions is crucial in the establishment and maintenance of natural vegetation, especially when dealing with drought-prone ecosystems. According to Regional Climate Models, the whole Brazilian territory is likely to face rainfall reductions and warmer days in the coming years. Hence, it may pose a threat to natural ecosystems productivity and to rainfed crops grown in soils with limited water supplying capacity. The objective of this study was to extend an earlier developed matric flux potential approach, adapting it for multi-layer scenarios; and to illustrate it using soil hydraulic properties in Brazilian layered soils from two agro-ecological zones: the semiarid zone and the sub-humid zone.

Materials and Methods

Soil data

Soils from two Brazilian climatic zones were studied, the semiarid and the sub-humid zone. The semiarid zone is located in the northeastern part of Brazil, and soils at three sites (sites 1, 2, and 3 , ***Figure 1***) representative of an integrally-preserved Caatinga watershed in Ceará State were sampled. The sub-humid zone occurs in a vast area covering the south, southeast and central parts of Brazil. To represent this region, eight sampling sites (sites 4-11 , ***Figure 1***) in São Paulo State were sampled. See also ***Table 1***.

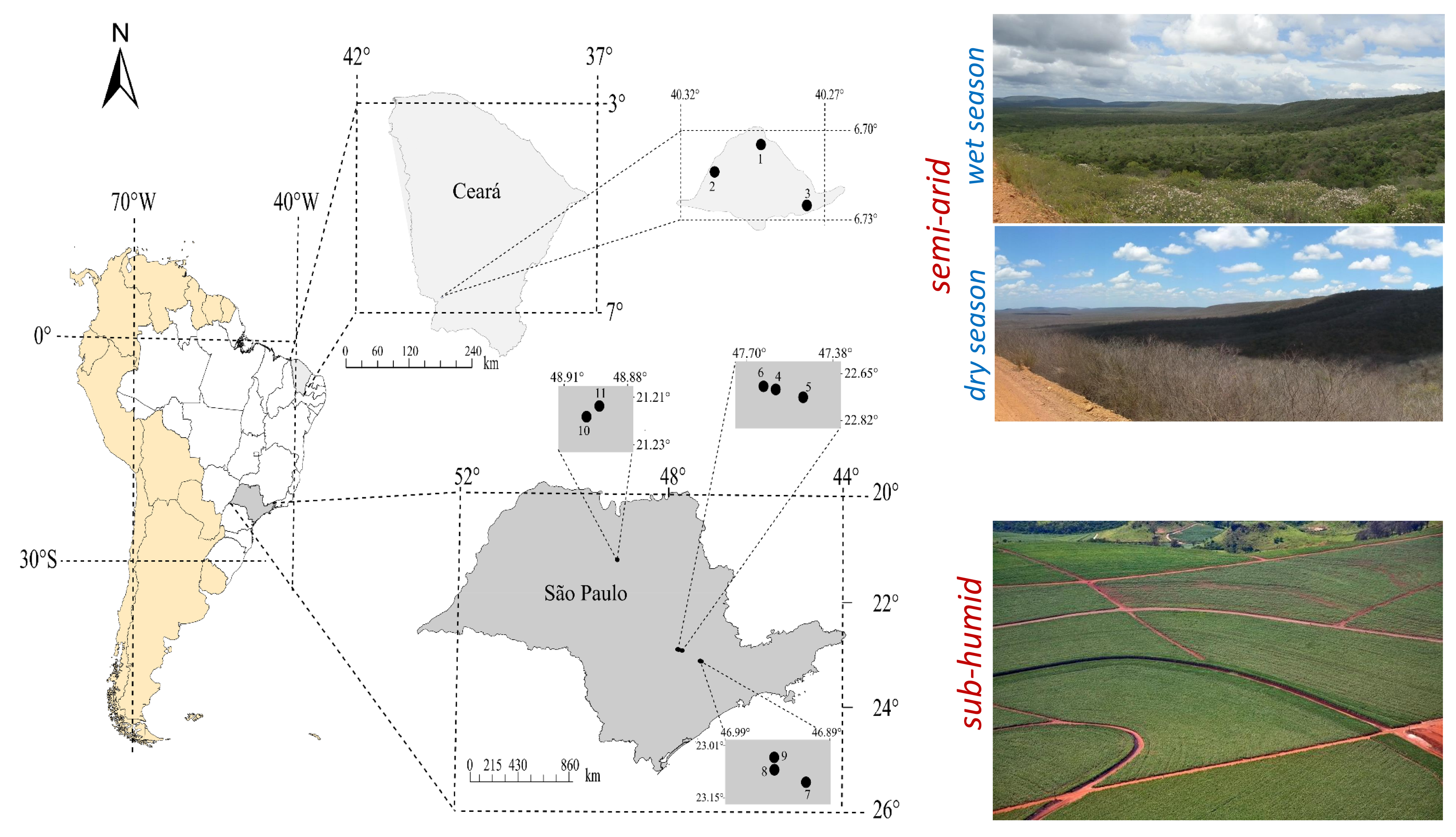

Figure 1 *– Geographical location of the sampling sites, semi-arid zone (1 - 3); sub-humid tropical and subtropical zones (4-11) and some illustrating pictures.*

Table 1 *– General characteristics of the sampling sites*

	Site #			
General characteristics	**1, 2, 3**	**4, 5, 6**	**7, 8, 9**	**10, 11**
Latitude	6.7° S	22.7° S	23.1° S	21.2° S
Average rainfall (mm y^{-1})	549	1300	1313	1258
Potential evapotranspiration - ETp (mm y^{-1})	2200	960	912	1094
Rainfall / ETp	0.25	1.35	1.44	1.15
Average temperature (ºC)				
annual	26.0	22.3	20.0	21.5
warmest month	28.0	25.3	22.0	23.8
coldest month	24.0	17.9	17.8	19.3
Vegetation type	Caatinga	Fallow	Orchard	Orchard
Köppen climate	Bsh	Cwa	Cwa	Aw

Soil hydraulic properties (*K*-θ-*h* relations described by the Van Genuchten-Mualem model) were assessed by inverse modeling of evaporation experiments equipped with polymer tensiometers.

A new limiting matric flux potential approach

A linear relation between the transpiration limiting matric flux potential M_{lim} (m^2 d^{-1}) and transpiration rate (T_p, m d^{-1}) with a zero intercept and a slope depending on the half-distance between roots (r_m, m) and the rooted soil depth *z* (m) was proposed by De Jong van Lier et al. (2006):

$$M_{lim} = p r_m^{\ q} \frac{T_p}{z}$$

p = 11.75 m^{2-q}
q = 2.367

This equation was adapted for a multi-layer condition, considering root water extraction proportional to layer thickness *L* (m) and to root length density *R* (m m^{-3}). Supposing *M* equal in all layers, the following expression was derived:

$$M_{lim}(z) = \frac{T_p p^*}{\sum_{i=1}^{n} R_i L_i}$$

p^* = 1.69:

To assess the water supply capacity of the investigated soil layers for both soil groups, we assumed a vegetation with a vertical root distribution with an average root length density *R* of 1000 m m^{-3} throughout the soil profile.

Results and Discussion

The limiting pressure head h_{lim} (the bulk soil pressure head at the onset of the falling-rate phase) calculated from M_{lim} showed lower in the semiarid soils (soils 1 - 3) than in sub-humid tropical and subtropical soils 4-11 (Table 2), suggesting that hydraulic properties of soils from the semiarid ecosystem allow root water uptake at a potential rate under a wider range of soil pressure heads.

Table 2 – Hydraulic conductivity K_{150} at h_w = -150 m and K_{300} at h_w = -300 m together with hydraulic conditions (h_{lim} [m] and Θ_{lim} [m^3 m^{-3}]) at the onset of the falling rate phase calculated for T_p = 6 mm d^{-1} and for limiting root water potentials (h_w) of -150 m and -300 m for all layers of the evaluated soils

	Sampling site #	Great soil Group IUSS (2015)	Depth	K_{150}	K_{300}	$h_{lim, 150}$	$h_{lim\ 300}$	$\Theta_{lim, 150}$	$\Theta_{lim, 300}$
			m	---m d^{-1}---		---m---		---m^3 m^{-3}---	
SEMIARID	1	Lixisol	0.00-0.20	$3.8\cdot10^{-8}$	$2.0\cdot10^{-9}$	-78	-81	0.13	0.12
			0.20-0.40	$3.0\cdot10^{-8}$	$1.4\cdot10^{-9}$	-75	-77	0.21	0.20
			0.40-0.60	$1.2\cdot10^{-8}$	$1.2\cdot10^{-10}$	-77	-77	0.15	0.15
			0.60-0.80	$2.4\cdot10^{-7}$	$9.3\cdot10^{-9}$	-118	-135	0.27	0.25
	2	Luvisol	0.00-0.20	$7.0\cdot10^{-8}$	$5.4\cdot10^{-9}$	-84	-90	0.31	0.30
			0.20-0.40	$7.2\cdot10^{-9}$	$3.7\cdot10^{-10}$	-47	-47	0.13	0.13
	3	Leptosol	0.00-0.20	$4.0\cdot10^{-9}$	$1.1\cdot10^{-10}$	-49	-49	0.38	0.38
			0.20-0.40	$2.9\cdot10^{-9}$	$1.7\cdot10^{-10}$	-33	-33	0.26	0.26
SUB-HUMID	4	Ferralsol	0.00-0.20	$1.2\cdot10^{-8}$	$2.7\cdot10^{-9}$	-18	-18	0.72	0.72
			0.20-0.40	$2.2\cdot10^{-8}$	$4.3\cdot10^{-9}$	-31	-32	0.63	0.62
	5	Nitisol	0.00-0.20	$2.3\cdot10^{-8}$	$4.3\cdot10^{-9}$	-27	-28	0.74	0.73
			0.20-0.40	$9.7\cdot10^{-9}$	$1.4\cdot10^{-9}$	-27	-27	0.39	0.39
	6	Luvisol	0.00-0.20	$1.5\cdot10^{-8}$	$3.4\cdot10^{-9}$	-21	-22	0.73	0.72
			0.20-0.40	$2.3\cdot10^{-8}$	$4.4\cdot10^{-9}$	-33	-35	0.60	0.59
	7	Ferralsol	0.00-0.15	$6.5\cdot10^{-9}$	$1.4\cdot10^{-9}$	-10	-10	0.72	0.72
			0.15-0.30	$3.9\cdot10^{-9}$	$9.3\cdot10^{-10}$	-6	-6	0.84	0.84
	8	Acrisol	0.00-0.30	$1.3\cdot10^{-8}$	$1.3\cdot10^{-9}$	-35	-35	0.60	0.60
			0.51-0.68	$2.9\cdot10^{-8}$	$4.6\cdot10^{-9}$	-36	-38	0.63	0.62
	9	Leptosol	0.40-0.60	$1.6\cdot10^{-8}$	$3.1\cdot10^{-9}$	-7.0	-7.0	0.76	0.76
	10	Cambisol	0.56-0.72	$5.3\cdot10^{-9}$	$1.3\cdot10^{-9}$	>-1.5	>-1.5	>0.99	>0.99
	11	Acrisol	0.00-0.15	$2.2\cdot10^{-9}$	$5.3\cdot10^{-10}$	>-1.5	>-1.5	>0.97	>0.97
			0.45-0.75	$1.9\cdot10^{-9}$	$4.0\cdot10^{-10}$	-3	-3	0.85	0.85

Conclusions

1. An existing matric flux potential approach to predict transpiration reduction was extended to multi-layer scenarios and used to identify soil water availability for soils of two Brazilian ecosystems.
2. Soils from the Brazilian semiarid zone are able to deliver water to plants under a wide range of soil pressure heads. On the other hand, soils from the wetter climatic zones show more hydraulic restrictions.
3. For the analyzed soils, only a negligible increase in available water results from decreasing the root water potential (h_w) below -150 m

Cited literature

De Jong van Lier, Q.; K. Metselaar, and J.C. Van Dam. 2006. Root Water Extraction and Limiting Soil Hydraulic Conditions Estimated by Numerical Simulation. Vadose Zone J. 5:1264–1277. doi:10.2136/vzj2006.0056

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