11.4 AN ANALOGIC MODEL OF WATER EXTRACTION BY GRASS ROOTS

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1. INTRODUCTION

The plant transpiration is the major water balance component in vegetated soils. Fluxes along the soil-plant-atmosphere continuum are regulated by above ground plant properties, like the leaf stomata, which can regulate plant transpiration when interacting with the atmosphere and below ground plant properties like depth, distribution, and activity of roots as well as soil physical properties like water potential, water content and hydraulic conductivity (Jackson et al., 2000).

The role of soil moisture within the soil-plant-atmosphere system depends on the soil moisture reservoir size and the availability of water in that reservoir, which in turns depends, in part, on the texture and structure of soil and the characteristics of the root system (Feddes et al., 2001).

There are two broad classes of modeling approaches for the root water uptake: the microscopic approach that considers the convergent radial flow of soil water toward and into the roots, taken as a uniform narrow-tube sink, and the macroscopic, a more hydrological approach that regards the root system as a diffuse sink added to the vertical water flow equation through the soil (Molz, 1981).

The purpose of this work was to fit and test, under field condictions during a soil drought period, an analogic macroscopic scale model of water extraction by grass roots, aiming at to evaluate the relative importance of soil and root resistances and their influence on plant water potential and transpiration over a wide range of soil moisture.

1.1. Theory

The basic one-dimensional differential equation for the soil water flux and root extraction is:

$$\partial\theta/\partial t = \partial\theta/\partial z\ [k\ (\partial\xi\ /\partial z) - k] - q_r \qquad (1)$$

where θ is the volumetric water content in the soil, t the time, z the soil depth, k the soil hydraulic conductivity, ξ the soil matric potential, and q_r the root extraction rate.

The single root model or microscopic approach (Federer, 1979) is the analytical solution for $\partial\theta/\partial t = 1/\nu\ \partial/\partial\nu\ (\nu\ k\ \ \partial\psi_s/\partial\nu)$ i.e :

$$q'_r = -\ [\ 2\ \pi\ k\ (\psi_r - \psi_s)\ ]\ /\ \ln\ (\nu_2/\nu_1) \qquad (2)$$

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where q' is the rate of water uptake per unit of root lenght, and ψ_r and ψ_s , the water potentials in the root surface (ν_1) and in the soil (ν_2). q' can be extended for a uniform root system by $q_r = q'_r\ z_r\ l_r$.

Root water extraction can also be expressed analogically to Ohm's law (Federer, 1979; Zur & Jones, 1981 and Hillel et al., 1976) by:

$$q_r = -(\psi_r-\psi_s)/r_s = -(\psi_p-\psi_r)/r_r = -(\psi_p-\psi_s)\ /\ (r_r+r_s) \qquad (3)$$

where ψ_p is the plant water potential, r_s the soil resistance (r_s = b/k), and b the root distance parameter (b= ln $(\nu_2/\nu_1)\ /\ 2\ \pi\ l_r z_r$)

A simulation model can be developed from the first equation combined with an analogic macroscopic root extraction function (eqn. 3):

$$\partial\theta/\partial t = \partial/\partial z\ [k\ (\partial\xi/\partial z)-k] + [\psi_p-\psi_s(z)]\ /\ [r_r(z)+r_s(z)] \qquad (4)$$

Supposing an exponential variation of b(z) and $r_r(z)$, due to the exponential decreasing in mass of the root system (Feddes et al, 1974) $w(z) = w(0)\exp(-\alpha z)$, $b(z) = b(0)\exp(\alpha z)$, and $r_r(z) = r_r\ (0)\exp(\alpha z)$ we have:

$$-[\psi_s(z)/q_r]\exp(-\alpha z)=\psi_p/q_r(z)\exp(-\alpha z)-b(0)/k(z)-r_r(0) \qquad (5)$$

Applying eqn. 5 to 3 or more layers at depths z we have the solutions for ψ_p, b(0), and $r_r(0)$. A combination of the 10 layers, 3 at a time, was used to derive a set of estimates for these 3 parameters.

2. DATA AND METHODS

The experiment was carried out at the University of São Paulo / Escola de Agricultura Luiz de Queiroz, county of Piracicaba, São Paulo, Brazil, located at 23^0S and 47^0W, at an altitude of 580m. The climate is Cwa according to Köppen´s classification with a typical rainy season from October to February. Annual average air temperature is 21^0C, and average rainfall is 1250mm.year^{-1}.

Vegetation cover is short grass (*Paspalum notatum,* Flügge*)* with 15cm height The mass distribution of the root system, fitted to field data collected at each 20cm, is: w = 0.0034 exp -0.014 z $[\text{g.cm}^{-3}]$.

The soil is a dark red latosol (Oxic Paleudalf), 2.2m depth, bulk density 1.46 g.cm^{-3}, and granulometry 35.2% sand, 19.5% silt, and 45.4% clay. The fitted drying soil water retention curve, obtained in laboratory using a pressure plate, is: $-\xi = 2.71.10^7$ exp -34.36 θ [cm], and the fitted soil hydraulic conductivity curve, obtained under field conditions using the method of

Rose et al. (1965), is: $k = 4.05.10^{-14} \exp 85.57\ \theta$ [$cm.day^{-1}$].

Average rates of water extraction by roots, for 20 cm soil layers, were estimated from 3 θ profiles, measured with a neutron probe at 3 days interval, in a dry sequence of 81 days, on August, September and October, by:

$$\int_{z1}^{z2}\int_{t1}^{t2} q_r(z)\,dz\,dt = \int_{t1}^{t2}(q_{z1}+q_{z2})\,dt - \int_{z1}^{z2}\int_{t1}^{t2}(\partial\theta/\partial t)\,dz\,dt \quad (6)$$

where ∂θ/∂t (eqn. 1) is solved using a forward finite difference method.

3. RESULTS AND DISCUSSION

Average water potentials in the soil (ψs), root (ψ_r), and plant (ψ_p) during the 27 dry periods of 3 days are shown in figure 1. ψs ranged from 1000 to 8000cm. ψ_p is almost constant (~3400 cm) until ψ_s = -3400 cm (17th period), increasing exponentially after this point, following ψ_r.

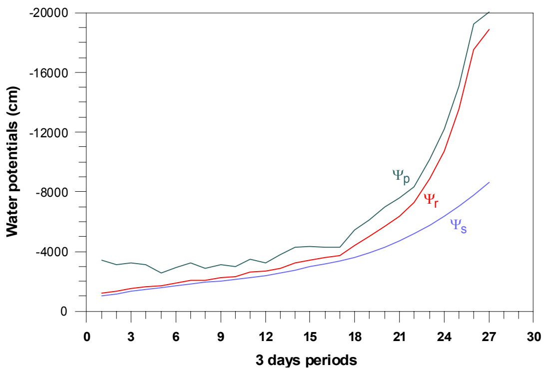

Figure 1. Average water potentials in the soil (ψ_s), root (ψ_r), and plant (ψ_p).

Average estimates of root distance b(0) and root resistance $r_r(0)$ were 2 ± 0.4 cm and 18000 ± 4000 days.

The soil (r_s=b/k) and root (r_r) resistances, as well the total resistance (r_s+r_r) to water flux from soil to plant, for the 27 periods of 3 days, are shown in figure 2.

Root resistances are almost constant (~8200days) and predominate until soil water potential ψ_s = -4300cm or k = $1.2.10^{-4}$ $cm.day^{-1}$ (20th period), increasing exponentially after this point. These results in agreement with Reicosky & Ritchie (1976), Federer (1979), and Zur et al. (1982), indicate that the root resistance to water transport is much greater than the soil resistance in a wide range of soil water content. These findings emphasize the need to consider root resistance in water uptake calculations when using equations that evaluate water potential gradients along the water flow paths.

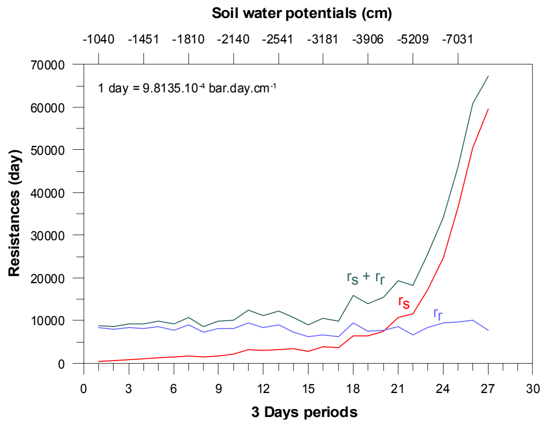

Figure 2. Resistances to water flux in the soil (r_s), and roots (r_r).

Figure 3 shows a comparison of soil water balance and model estimates of root extraction rates in a 81-days soil drought period. The extraction rates decrease with soil water potentials until ψ_s = -2900cm.

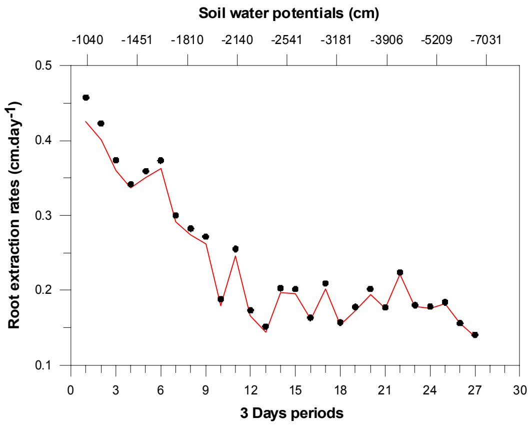

Figure 3. Soil water balance (dots) and model estimates (line) of root extraction rates in a 81-days soil drought period.

The fitted analogic model reproduced very well the original root extraction rates used in the model calibration and may be used to study the dynamics of the complexes interactions among soil, plant and atmosphere.

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