Diurnal evolution of water flow and potential in an individual spruce: experimental and theoretical study

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Introduction

We present a model built primarily to study the water flow in a single tree within a forest. After comparing it with other available systems, we develop the characteristics of our model and its usefulness.

Materials and Methods

Outline of the model

The structure of the model (Fig. 1) comes from our idea of how the spruce we work with is compartmented; 7 compartments were distinguished: leaves (1), uppercrown (2), lower crown (2), trunk (2). Except for leaves, 2 kinds of water reservoirs constitute each of the 3 preceding levels (Jarvis, 1975; Granier, 1987; Granier and Claustres, 1989): a small one corresponding to the elastic tissues with a small constant of time and a larger one representing the sapwood with a large time constant. Twelve resistances must be specified. Although SPICE, the circuit simulation program we used, allows us to introduce variable capacitances and resistances (Cruiziat and Thomas, 1988), we did not think they were necessary at this stage of our experimental knowledge.

Assumptions

1. Sap moves from points of high potential to points of low potential. 2. Flow within the different parts of the system obeys the Darcy equation. 3. Roots are not supposed to have a capacitance (optional). 4. All parameters are lumped together. 5. Neither branch, twig architecture nor growth are considered (optional).

Values of the parameters and input variables

The data consist of hourly measurements of sap flow (bottom of the trunk), leaf water potential at 2 levels and transpiration rate per tree (calculated by the Penman–Monteith equation for the stand). In addition, sapwood cross sectional area and dimensional characteristics at different levels provide information for starting values of the parameters (resistances and capacitances). Then they were adjusted (by trial and error) in order to obtain a combination of values which reasonably fit our measurements.

Properties

Under 'ideal' conditions (regular transpiration, all potentials, including ψ_{soil} starting at 0 MPa), there is a continuous evolution of ψ in the different parts of the tree (Fig. 2); only the reservoirs from elastic tissues show no residual deficit at the end of the night; the sapwood tissue still stays at a negative ψ; its contribution is about 3% of the daily transpiration. This
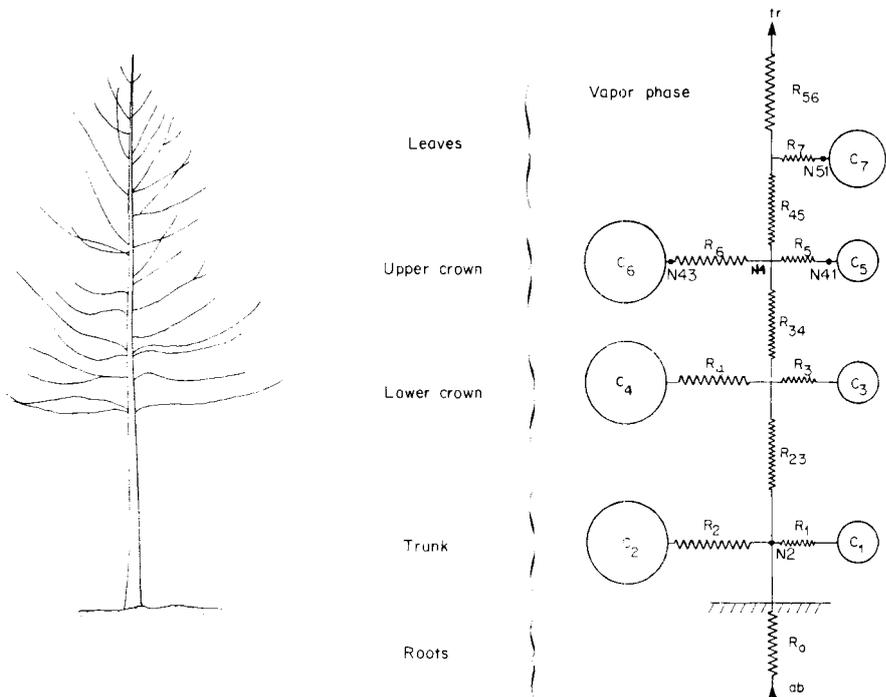
Fig. 1. The working model of water movement in a *Picea abies* tree within a stand. It is made of 7 reservoirs (C_1–C_7) and 12 resistances: C_1, C_3 and C_5, represent the reservoirs of elastic tissues; C_2, C_4 and C_6, those of the sapwood at 3 different levels in the trunk. C_7 is the leaf reservoir. Values of these parameters constitute the inputs together with transpiration and soil water potential. The simulation gives flow and potentials at different nodes.

proportion increases gradually if the ψ_{soil} falls for several days.

The difference between maximum rates of transpiration (E_{max}) and absorption is greatly affected by the relative magnitude of root resistance.

The minimum value of ψ_{leaves} occurs leaves about 1 h after (E_{max}): at that time, transpiration and absorption are equal. This fact provides a means to obtain an estimation of the total resistance of the transpirational pathway (Fig. 3).

It is possible to determine the 3 parameters (2 resistances and 1 capacitance) of the equivalent circuit having the same transfer function (= transpiration *versus* absorption). This transformation allows those interested in water

balance of drainage basins to use this simplified version as a submodel.

Discussion and Conclusions

This model was designed to be a working tool. It has 2 main purposes: 1) to continuously bring together new experimental data within a coherent representation; and 2) to help us to select the most crucial measurements. Our model differs from
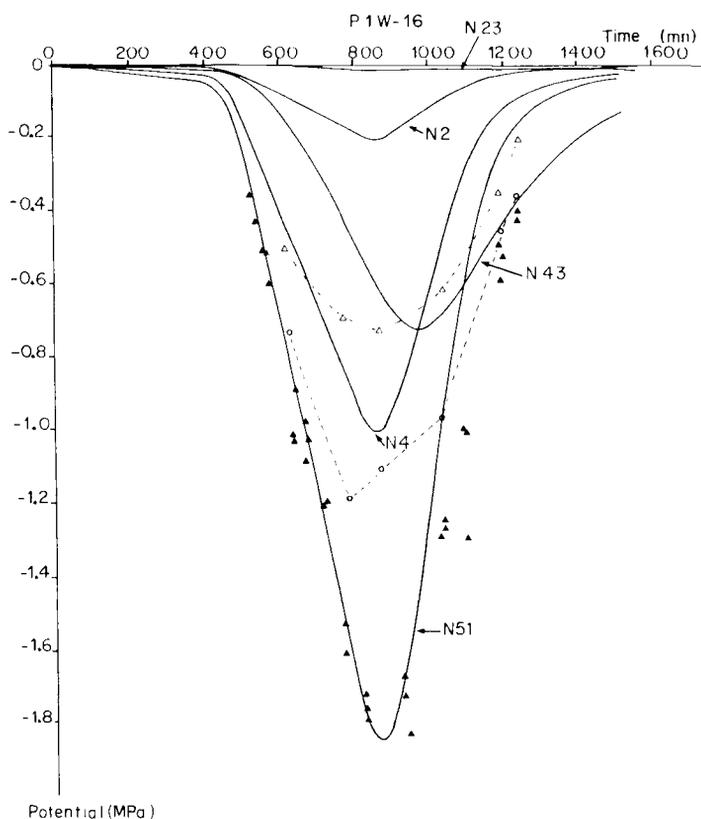
Fig. 2. Real and simulated water potential (same tree as Figs. 1 and 3). N_2–N_{51} refer to nodes as indicated in Fig. 1. ▲-▲: water potential data of twigs from the upper crown; water potential of non-transpiring bagged leaves from upper (o--o) or lower (Δ--Δ) crown.

other published models (Landsberg *et al.,* 1976; Milne and Young, 1985; Wronski *et al.,* 1985; Edward *et al.,* 1986) by its structure. Nevertheless, for the moment, due to the lack of experimental data, it is likely that several models of the same object (*e.g.,* same species) can be presented, each having its own strengths and weaknesses. Therefore, we believe that it is more useful to compare different approaches to the same object rather than different models designed for different objects.

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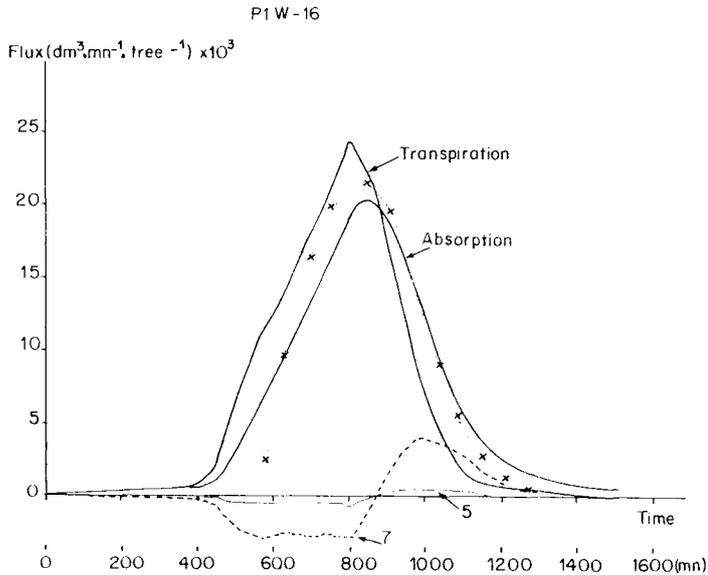Edwards W.R.N., Jarvis P.G., Landsberg J.J. & Talbot H. (1986) A dynamic model for studying

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Flux (dm^3.mn^{-1}. tree $^{-1}$) x10^3

Fig. 3. Real and simulated water flow in the trunk during a day for a *Picea* tree within a stand. Transpiration is an input variable, absorption and flow 5 and 7 are simulated; 7 refers to the flow of the leaves and 5 refers to the flow from elastic tissues in the upper crown. The dotted line represents the measured flow at the bottom of the trunk.

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