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Water movement and its resistance in young trees of *Cryptomeria japonica*

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Introduction

Information about water flow resistance is essential to understanding and simulating water movement in trees (Yahata, 1987). There are a number of papers concerned with it for some species but few for *Cryptomeria japonica* and no data are available on the gradient of water potential in intact stem. This study was undertaken to examine whether the resistance in stems would be regarded as substantially constant all day long and to find a simple equation to predict the effect of stem form on it.

Materials and Methods

14 yr old *C. japonica* trees growing in a plantation of high stand density about 6650 stems per ha were used. Psychrometer sensors (Wescor PCT55-30) were used with an automated recording system for measuring the water potential of soil at a depth of 20 cm and rootstock at 10 cm, and a Scholander pressure chamber for shoots. The sensors were placed and sealed in small drilled holes in the stem and rootstock. Diurnal variation of the ambient temperature of the sensors was minimized to within less than 1°C by the use of insulating materials to reduce errors from temperature gradients. Transpiration rates were estimated by the measurement of leaf conductance to water vapor and the ambient vapor deficit between leaf and air. The water flow rates in the stem at different heights (0.5–2.5 m) were estimated using the relationships between the heat–pulse velocity, measured with an automatic multichannel recording system (Yahata, 1984) and the water uptake rates from the severed basal stem at the end of a series of measurements of the intact tree. Sapwood conducting area was measured by using a dye (1% solution of acid fuchsine).

Water flow rate, Q, is customarily expressed as an Ohm's law analogy with resistance, R, and the water potential gradient, $\Delta\psi$, in the following equation (eqn. 1). $Q = (\Delta\psi - \rho gh)/R$, where ρgh is the gravitational potential at a height of h (m). By using the above equation with the water flow rate in the stem in place of Q and the gradients of water potential between soil and leaves, $\Delta\psi_{s-l}$, or between rootstock and leaves, $\Delta\psi_{r-l}$, the resistance of total pathway, R_{spac}, and between root and leaves, R_x, and between soil and root, R_{s+r}, were determined, respectively.

Provided that the relative resistance r_r (m^{-2}), as defined by Jarvis (1975), is constant throughout a stem with a length of l (m), total resistance R_{xcal} ($Pa \cdot s \cdot m^{-3}$) can be written as follows (eqn. 2): $R_{\mathrm{xcal}} = \int^{l}_{l=0} (r_r \eta / A)\, dl = r_r\, \eta\, l_a$, where $l_a = \int (1/A)\, dl$, which can be considered to be an index of resistance based on stem form, and A is the cross-sectional area of sapwood, and η is the viscosity of water ($N \cdot s \cdot m^{-2}$).

Results

On the clear day of August 20th, when the soil was dry, the predawn water potential of leaves was 0.2–0.3 MPa lower than the soil. On the other hand, the water potential of rootstock was higher by about 0.1 MPa than the soil and began to decrease after sunrise slowing after the leaves and became lower than the soil about 9:00. It was confirmed here, too, that water movement occurred along the water potential gradient of soil, rootstock and leaves during daytime, but reverse gradients of water potential of about 0.1 MPa were observed at night and in the early morning when the water flow declined.

Fig. 1 shows the relationships between the water potential gradient and the water movement in the tree. Linear regression curves intersecting at ρgh = 0.0608 MPa on the axis of ordinates fitted the observations better. The computed resistance of total pathway, R_{spac}, of stem, R_x, and of the pathway from soil to rootstock, R_{s+r}, were 8987, 7218 and 1769 MPa·s·kg^{-1} (= x10^3 MPa·s·m^{-3}), respectively, by using the water flow in place of Q. When transpiration was used instead of the water flow, the resistances were slightly lower but there were no substantial differences in the resistance. While the resistance measured in the forenoon was larger than that in the afternoon, especially, for R_x, when estimated with the water flow, they were reversed when estimated with transpiration. This seems a quite predictable result when taking account of the time lag between water flow in the canopy and in the stem. Furthermore, using the data of water flow in the stem, there was a larger diurnal variation of R_x than of R_{spac}. This variation is considered to result from the fact that the relative distance of the measuring point for water flow was very close to the measuring point for water potential of rootstock. In order to keep a steady state, it is considered that the measuring point for water flow should be located in the middle of the range of the points for water potential. Therefore, in the following experiment, the water potential gradients in the stem between 0 and 3 m aboveground and water flow rates between the 2 points were measured. As a result, no essential diurnal changes of resistance were observed, and the R_{x3}, the resistance between 0 and 3 m, was 2006 MPa·s·kg^{-1}.

The changes in I_a calculated with the cross-sectional areas of sapwood indicate that I_a is very small in the lower part of the stem and increases with height of the stem. The value of r_r, estimated by eqn. 2 using the value of I_a up to 3.0 m and R_{x3}, was 2.11 x 10^{12} m^{-2}.

As an example of the calculation of eqn. 2, an effect of reducing the water flow pathway on the index of resistance, I_a, was examined, providing that the cross-sectional area of sapwood at 1 m high was reduced to 5 cm^2 and the permeability was lost with a thickness of 10 cm. It is clear that the influence was small compared to the resistance of water flow.

In Fig. 2, using the above equation, resistance between stem base and 0.5 m below the top of trees and the water flow rates to the top shoot when the water potential gradient was 1 MPa, were calculated. In this calculation, the equation of relative stem form and the yield table published for *C. japonica* were used. At the beginning of the growth stage, the calculated resistance $R_{x\mathrm{cal}}$ increased with height growth up to about 5 m, and subsequently the increasing rate declined. The width of sapwood, which was considered to be almost constant vertically throughout the stem, did not affect the resistance and the water flow, but the stem forms did significantly affect the resistance and the water flow.

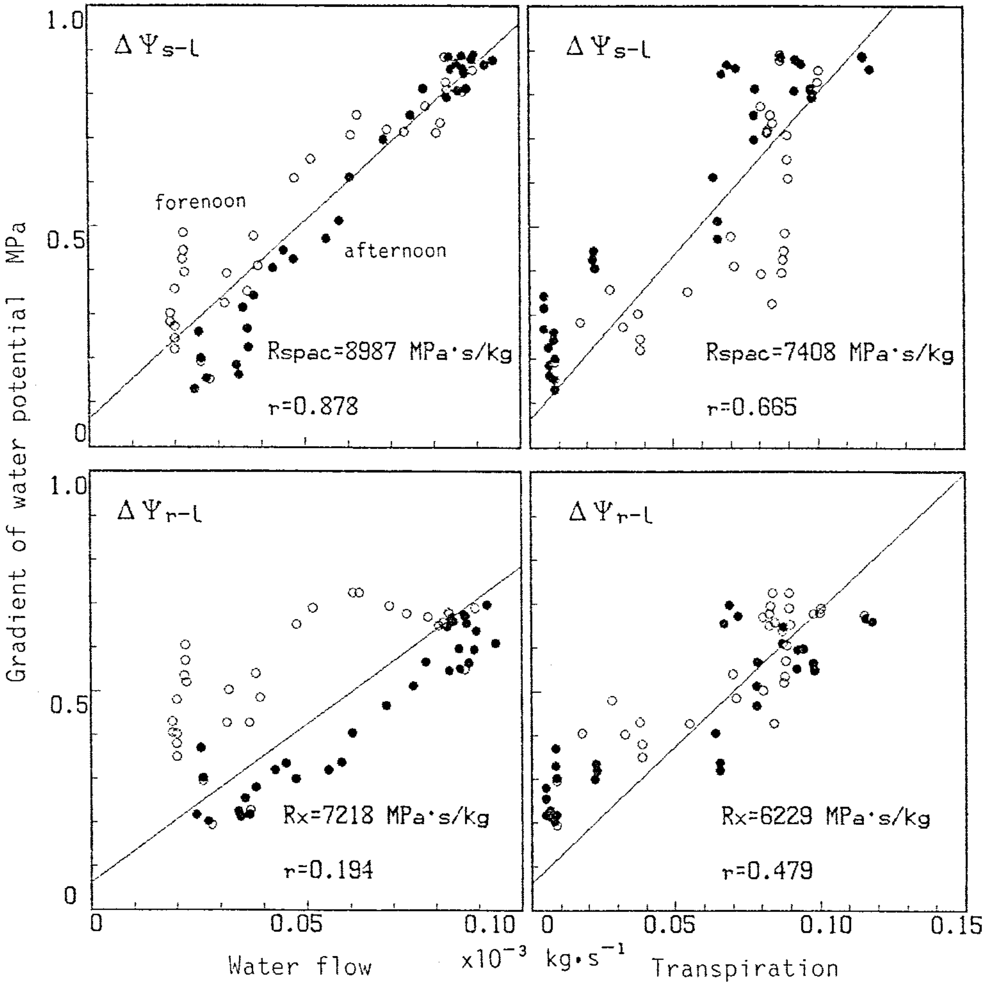

Fig. 1. Relationships between water potential gradients and rates of water flow or transpiration.

Discussion and Conclusion

It was confirmed that there is a gradient of water potential along the pathway of water flow, but there was a reverse gradient between soil and rootstock when the water flow declined. This result might suggest the possibility of real active water uptake by roots. However, further study is necessary to include the possibility.

Diurnal changes in the resistance to water flow have been reported, the resistance tending to rise in the afternoon (Nnyamah *et al.,* 1978). Nevertheless, the

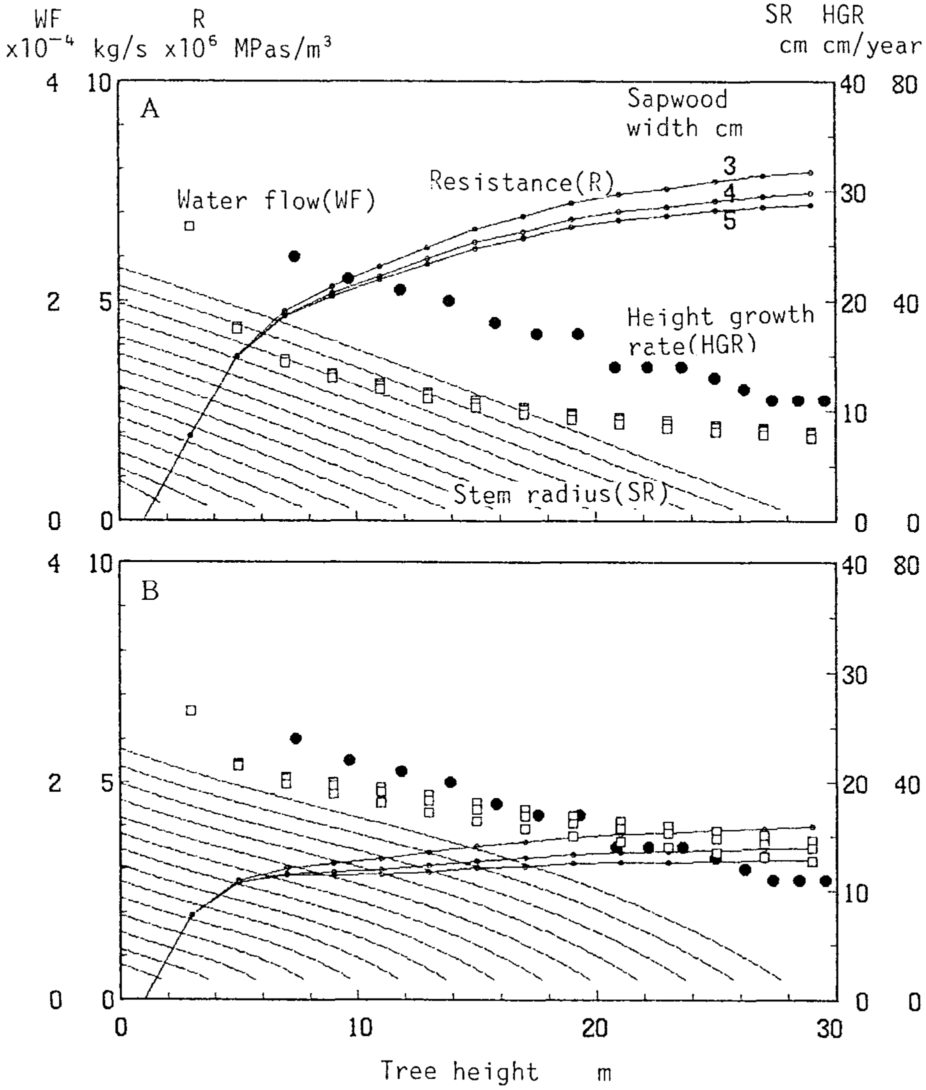

Fig. 2. Calculated result showing the effect of height growth, stem form and sapwood width on resistance and water flow to the top shoots.

measuring point of water flow in relation to those of water potential could possibly cause the diurnal change. It is probable that the resistance to water flow in the stem is substantially constant for *C. japonica.*

Although eqn. 2 for predicting the effect of stem form and growth on the water stress to the top shoot should be tested in practice, it could provide a simple model of the effect on the water movement in stems.

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