11. THE ROLE AND USE OF WATER IN SITKA SPRUCE PLANTATIONS

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Rain falling on a forest can be partitioned into 3 major components:

Throughfall—the fraction falling on ground directly or dripping from branches

Stemflow—the part collected on branches and running to soil via tree trunks

Interception—the fraction trapped on branches and needles and evaporated back to the atmosphere.

Water reaching the ground either flows to streams and rivers, Runoff, or is taken up through plant roots and foliage, passing through stems into the Transpiration stream.

It goes without saying that the partitioning of rainfall can greatly affect plant growth, and that the use of water influences the effects of afforestation on the water budgets of upland catchments. **Ford & Deans (1978) and Deans (1979) found** that patterns of root growth reflected changes, both in time and space, of soil moisture, and there are indications that the internal availability of water may affect shoot and cambium growth of trees.

The results will be considered in relation to:

i) Transpiration and the partitioning of rainfall.
ii) Internal moisture stress.

1) Transpiration and rainfall partitioning

The theory of transpiration and evaporation has been well argued (eg Jarvis & Stewart, 1978) but it needs to be validated by greater numbers of experimental measurements of water loss from differing forest sites. Staff of ITE have concentrated on the measurement of transpiration from the dry canopy of Sitka spruce planted in 1962 at Rivox Moor within Greskine Forest. The investigation has exploited the development of energy balances and techniques, the use of the eddy correlation method to estimate the flux of latent heat and thence the canopy resistance to water loss from stomata, assessments being made during periods of 6 days in 1976 (Milne, 1979) and 1978.

In a forest, with a constant canopy temperature, energy from the sun is partitioned into 3 fractions, those (a) going into the soil, (b) lost in the transpiration stream and (c) lost as a sensible heat flux by the turbulent convection of warm air. **Thus latent heat flux (λE) can be estimated from —**

$$\lambda E = R_N - G - H \qquad (1)$$

where R_N = net radiation
G = soil heat flux
H = convective or sensible heat flux

H, the sensible heat flux, was estimated using the eddy correlation method (Dyer *et al.,* 1967)

$$H = \rho c_p \overline{w'T'} \qquad (2)$$

Where ρ and c_p are the density and specific heat of air respectively, W is the vertical wind speed and T is air temperature.

The bar above w' and T' denotes a time average and the prime, as in w', a deviation from the mean.

Vertical wind speed was measured by a horizontally mounted Gill anemometer and air temperature by a fast response beam thermistor both of which were 2 m above the 7 m tall forest. The outputs of the anemometer and thermistor were connected to a 'Fluxatron' circuit (Hicks, 1970) which produced a signal proportional to instantaneous sensible heat flux. This signal was averaged over periods of 20 minutes by an analogue/digital circuit, the averages then being recorded with a computer controlled data logger.

Transpiration from a dry canopy is given by the Penman-Monteith equation (Monteith, 1965):

$$\lambda E = \frac{\Delta (R_N - G) + \rho c_p (\delta e / r_a)}{\Delta + \gamma . (1 + r_c / r_a)} \qquad (3)$$

where Δ = the slope of the saturation vapour curve
δe = the vapour pressure deficit of air
γ = the psychrometric constant
r_a = the resistance to transfer of heat or water vapour (assumed to be the same) in the atmospheric boundary layer
r_c = the resistance to transfer of water vapour from canopy (ie net effect of all stomatal resistances)
E = the transpiration as a mass flow
λ = the latent heat of evaporation of water

Using the Bowen ratio, β (=H/λE,) equation (3) can be rearranged to give the following estimate for canopy resistance:

$$r_c = (\beta\Delta/\gamma - 1).\ r_a + (\rho c_p/\gamma).\ (\beta+1).\ (\delta e/(R_N - G)) \quad (4)$$

During an experimental period in July/August 1976 the mean transpiration rate of Sitka spruce was 3 mm/day implying that each of the 4700 trees/ha lost about 6 litres of water daily. Because Ford and Deans (1978) found, when studying the same stand of Sitka spruce, that the average input of rain to soil was about 7.5 litres/tree per day in the period from May to August, it seems that transpiration during these summer months removes most of the rain falling on the ground. When an allowance is additionally made for runoff, there can be no doubt that moisture potentials are likely to fall below -0.17 bar, a potential with which the death of fine roots at Rivox is associated (Deans, 1979).

Generally it was found that changes in rates of transpiration within a day were significantly correlated with radiation changes, a feature confirmed by measurements of shoot water potential. Typically, transpiration was maximal just after mid-day (Figure 27); Bowen ratios ranged from 0.0 to 1.5 with canopy resistance usually cycling from 150 sm^{-1} shortly after dawn to 40 sm^{-1} by early/mid-morning with a return to >100 sm^{-1} by evening (Figure 28).

Comparisons made with published results from other UK sites (Jarvis *et al.*, 1976) suggest that generalisations should not be made about either the response of a single species in different locations or the response of a range of species growing in the same weather conditions, until more is known of the interactions between trees and their forest environments. To this end the use of a null balance porometer was included when assessing stomatal resistance of Sitka spruce needles in an extended collaborative project done in 1978 with Prof. P.G. Jarvis. With this direct method of assessing stomatal resistances it should be possible to check the validity of the estimates obtained indirectly from equation (3).

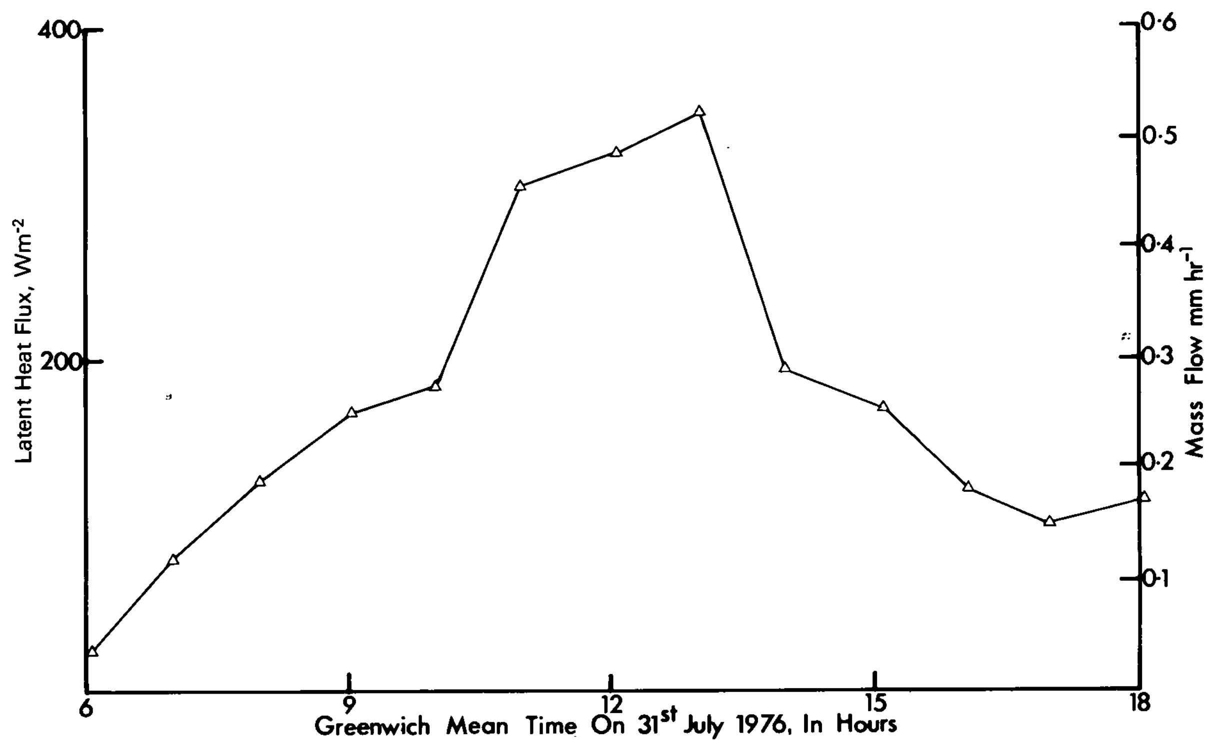

Fig. 27 *The diurnally changing rates of transpiration from a Sitka spruce plantation at Rivox Moor, Greskine forest, Scotland, transpiration being expressed as either latent heat flux or mass flow.*

For the future, it seems that advances will depend, to some considerable extent, on the development of more sophisticated instruments to aid:

a. replacement of existing hybrid systems for calculating average heat fluxes from vertical wind speed and air temperature measurements by an integrated system based on the Rockwell AIM 65 microcomputer using the R6500 chip set;

b. replacement of the Fluxatron propellor anemometer by a simple cheap sonic anemometer which should be more responsive to small eddies thus minimizing the inevitable underestimates incurred at present and possibly

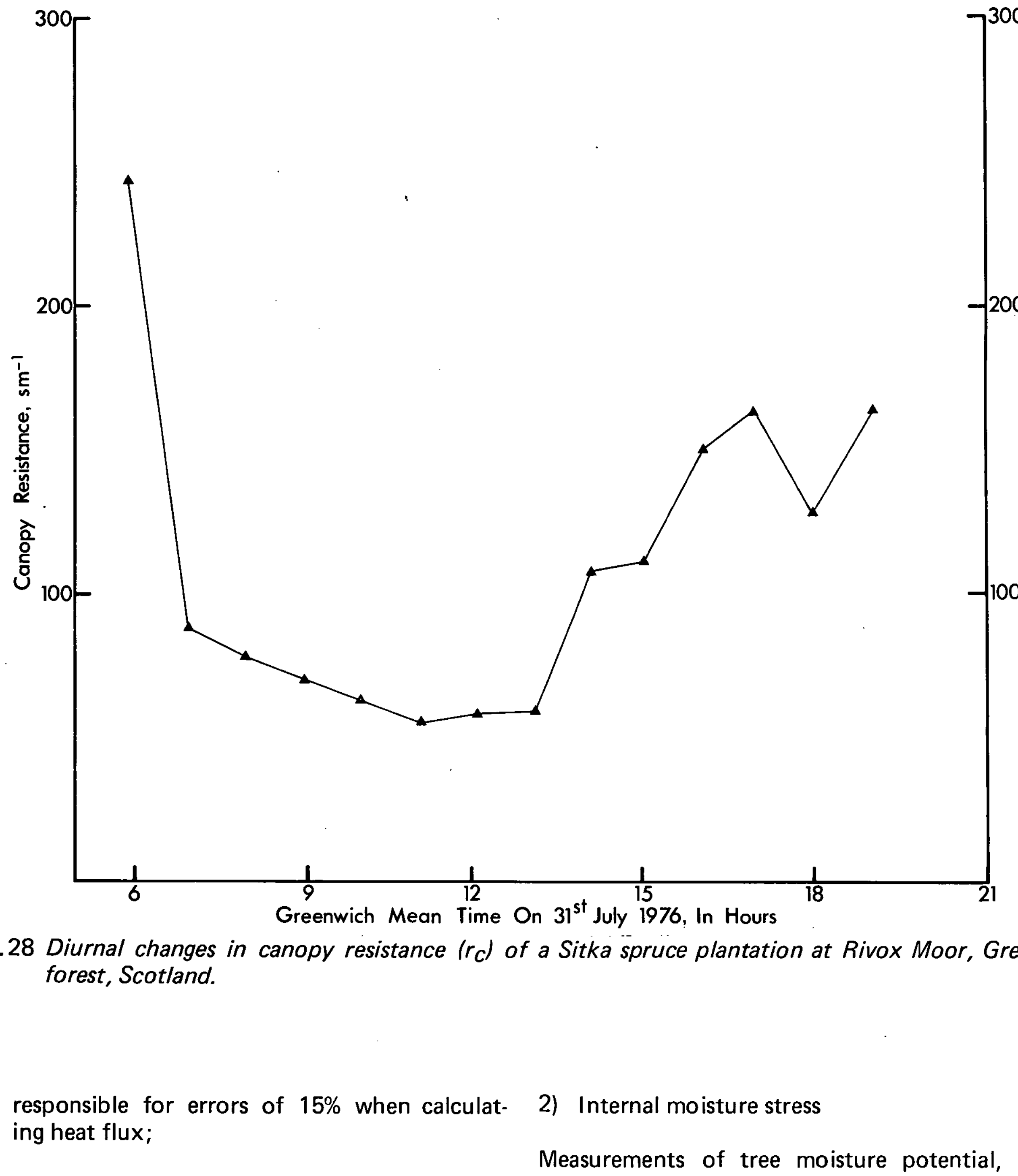

Fig. 28 *Diurnal changes in canopy resistance (r_c) of a Sitka spruce plantation at Rivox Moor, Greskine forest, Scotland.*

responsible for errors of 15% when calculating heat flux;

c. direct measurement of latent heat flux (transpiration) by linking a humidity sensor with the vertical wind speed sensor in the sensing head of the Fluxatron;

d. for measuring rainfall, throughfall and stemflow over short time scales with a resolution of 0.005 mm but able to cope with amounts up to 250 mm per hour. These requirements are necessary because work done on rainfall partitioning by other members of the ITE team (Ford & Deans, 1978) is based on weekly samples which are too coarse to permit either detailed analyses of individual storms or comparisons with published models (Rutter *et. al.*, 1971).

2) Internal moisture stress

Measurements of tree moisture potential, using a pressure bomb, and of changes in stem diameter taken at hourly intervals have been made on a number of occasions, the data subsequently being analysed using discrete difference equation models (Box & Jenkins, 1970). As yet the relation of changing moisture storage, within plant cells, and the physical environment has not been satisfactorily elucidated. More recently, detailed measurements of tree moisture potential and stem diameters have been supported by estimates of canopy water losses using energy balance/eddy correlation methods. The data obtained should enable models of the resistance–capacitance analogue type (Jones, 1978, Landsberg *et al.*, 1976) to be developed, compared with the Box-Jenkins version and hence used in relating transpiration flows in the atmosphere with events actually occurring within trees.

References

Box, G.E.P. & Jenkins, G.M. 1970. *Time series analysis.* San Francisco: Holden Day.

Deans, J.D. 1979. Fluctuations of the soil environment and fine root growth in a young Sitka spruce plantation. *Pl. Soil,* 52, 195-208.

Dyer, J.A., Hicks, B.B. & King, K.M. 1967. The Fluxatron—a revised approach to the measurement of eddy fluxes in the lower atmosphere. *J. appl. Meteorol,* **6**, 408-413.

Ford, E.D. & Deans, J.D. 1978. The influence of canopy structure on the pattern of rainfall distribution to the floor of a Sitka spruce plantation. *J. appl. Ecol.,* **15**, 905-917.

Hicks, B.B. 1970. The measurement of atmospheric fluxes near the surface: a generalized approach. *J. appl. Meteorol.,* **9**, 386-388.

Jarvis, P.G., James, G.B., & Landsberg, J.J. 1976. Coniferous forest. In: *Vegetation and the atmosphere, 2: Case studies,* edited by J.L. Monteith, 171-240. London: Academic Press.

Jarvis, P.G. & Stewart, J. 1978. Evaporation of water from plantation forest, In: *The ecology of even-aged forest plantations,* edited by E.D. Ford, D.C. Malcolm and J. Atterson, 327-349. Cambridge: Institute of Terrestrial Ecology.

Jones, H.G. 1978. Modelling diurnal trends of leaf water potential in transpiring wheat. *J. appl. Ecol.,* **15**, 613-626.

Landsberg, J.J., Blanchard, T.W. & Warrit, B. 1976. Studies on the movement of water through apple trees. *J. exp. Bot.,* **27**, 579-596.

Milne, R. 1979. Water loss and canopy resistance of a young Sitka spruce plantation. *Boundary-Layer Meteorol.,* **16**, 67-81.

Monteith, J.L. 1965. Evaporation and environment. In: *The state and movement of water in living organisms,* 205-234. Cambridge: Cambridge University Press. (Symp. Soc. exp. Biol. no. 19).

Rutter, A.J., Kershaw, K.A., Robins, P.C. & Morton, A.J. 1971. A predictive model of rainfall interception in forests. I. Derivation of the model from observations in a plantation of Corsican pine. *Agric. Meteorol.,* **9**, 367-384.