DESIGN OF A NEW WEIGHING LYSIMETER FOR MEASURING WATER USE BY INDIVIDUAL TREES

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ABSTRACT

A weighing lysimeter has been designed which directly measures water loss or gain by an individual tree up to 20 m tall. For a gross load of 2.5 tonnes, weight changes as small as 0.15 kg can be recorded – a resolution of more than 1 in 16 000. On the basis of the ground area occupied by the tree crown, the resolution in evaporation terms is 0.01 mm.

The data accumulated will be incorporated in long-term studies of water use by **Pinus radiata** D. Don forest.

INTRODUCTION

When estimating water use by forest it is necessary to make measurements of the absolute quantities of water transpired from dry canopies or evaporated from wet canopies. Measurements are often made on parts of individual trees and these results are multiplied up to a single tree and thence to the whole canopy. These data provide the necessary base for making predictions of water use by forest and can subsequently be used to predict the effects of afforestation or deforestation on catchment water balances. One direct method of obtaining such data for whole trees is the use of a weighing lysimeter. However, in order to reliably extrapolate lysimeter results to a forest stand it is important that the tree growing in the lysimeter is representative of the stand, and replication is desirable. Obviously a simple, low cost, reliable design is essential if more than one lysimeter is to be built.

Given these criteria, six weighing lysimeters were built at one site in Rotorua in conjunction with a research programme on water use by *P. radiata* forest. Three of the lysimeters are now operational and the other three are being completed. The design features are described and discussed here, with examples of calibration and some experimental results. Further data will be presented elsewhere.

LYSIMETER DESIGN

In 1973 a small (0.5 ha) *P. radiata* plantation was established near the Forest Research Institute, Rotorua ,around a layout of six concrete-lined pits each containing a steel container 1.2 m deep and 1.8 m in diameter. The containers were carefully filled with soil to re-create the original profile as nearly as possible. They were planted with rooted cuttings of *P. radiata,* and rooted cuttings and seedlings were planted throughout the area at the same time. The lysimeter weighing mechanisms were not installed until later. At present the 9-year-old trees are 13 m tall and at a spacing giving 762 stems/ha. The three units now operational contain trees from the same clone.

Rose *et al.* (1966) briefly reviewed weighing mechanisms for lysimeters and concluded that a hydraulic system most readily satisfied their requirements. McIlroy & Sumner (1961), Puckridge (1978), and Reyanga *et al.* (1979) used a lysimeter tank suspended by steel cable from a supporting pivoted balance arm. Changes in weight were recorded from movements in the position of the arm. All of these weighing systems were built underground. Le Drew & Emerick (1974) designed an above-ground weighing system in which the weight of the lysimeter was balanced on a pivot supported on a fulcrum against a counterweight. Fritschen *et al.* (1973) designed a hydraulic system to measure weight changes in a 28-m-tall *Pseudotsuga menziesii* (Mirb.) Franco tree.

In forest stands, as opposed to areas with short vegetation, it is highly unlikely that above-ground structures will significantly affect the environmental gradients below the canopy. Furthermore, at our study site it was important to avoid extensive underground excavation since the plantation had already been established. It was also desirable to avoid the complexities of a hydraulic mechanism.

The design chosen on these grounds is shown diagrammatically (Fig. 1) and as installed (Fig. 2). Full details of materials used and construction methods have been given by Gifford & Thomas (1983). Each container is suspended from three steel beams resting on knife-edge pivots, with the load of the lysimeter counterbalanced by two movable concrete slabs on the end of each beam. Connection between the triangular steel base of the container and each beam is by a galvanised chain. It was important in building the beam assemblies that distances between fittings on all three beams were identical. Above and below each beam, matched pairs of opposing springs which are always under tension damp oscillations and reduce noise in short-term (1-second) measurements of beam position. Apart from the damping effect, the springs cause the beam to operate as a spring balance, so changing the calibration factor of the lysimeter according to the tensile strength of the springs.

Vertical changes in beam position caused by a change in the weight in the container are measured using linear voltage differential transformers (LVDT) (Model Number 3000 HR with signal conditioner LPM-210, Schaevitz Inc., United States) at the extremity of each beam. The cumulative outputs from the LVDT linked in series, are converted into frequencies, and 1-second counts are accumulated over hourly periods at a remote data logger where totals are punched on to paper tape. The body of the LVDT is bolted to a plywood plate and a wooden post to ensure minimal temperature sensitivity, and the core of the LVDT is attached to the assembly at the end of the beam with nylon threads.

When setting up the lysimeter for operation, the positions of the counterweights are adjusted until the beams are horizontal and supporting the weight of the container. The beams are locked in position, equal tension is applied to each pair of springs, the

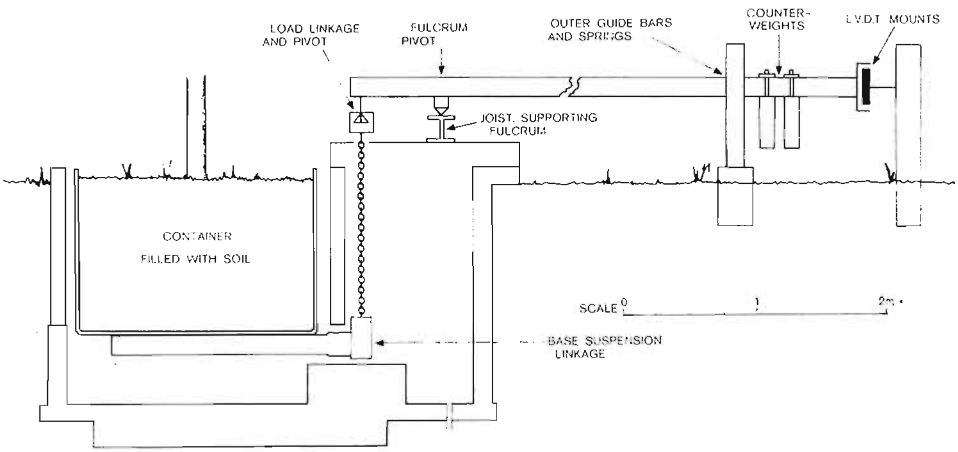

FIG. 1—Cross-section through lysimeter container and one beam and fittings, showing location of main components.

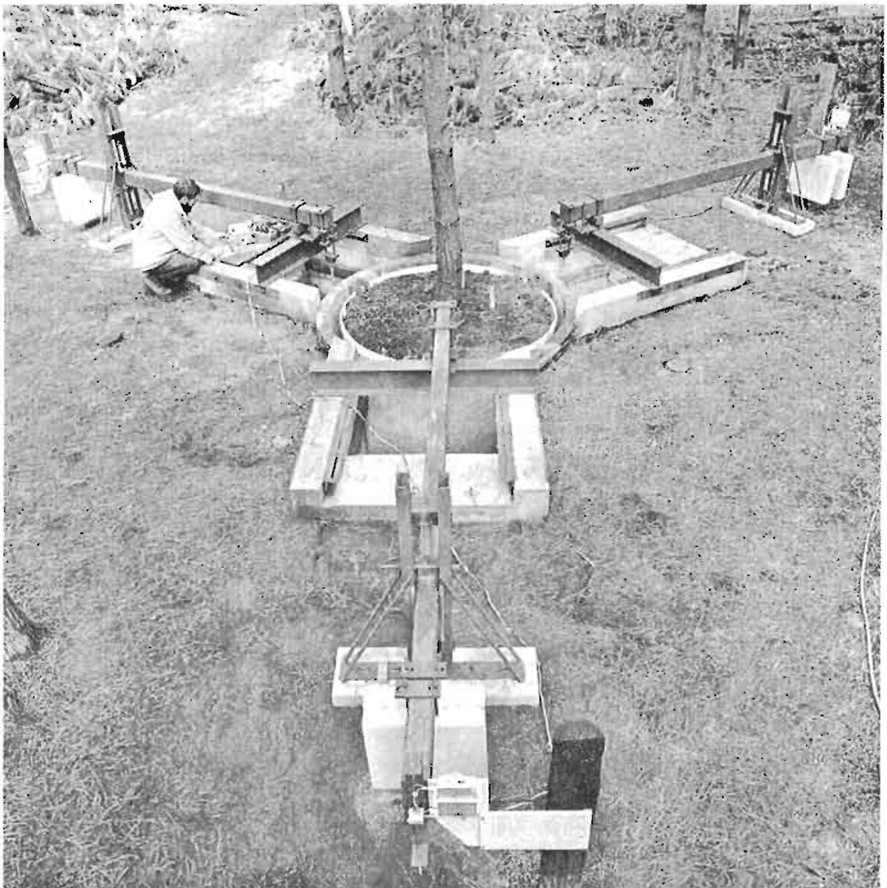

FIG. 2—View of complete lysimeter in operation.

LVDT are attached and adjusted so the output frequency is in the centre of its range, the beams are unlocked, and the lysimeter is ready.

The main problem with a lysimeter designed to contain a large tree is instability. Even when all three beams are balanced and level, small disturbances caused by wind-sway can cause the system to tilt out of equilibrium. This results in variation in the output from the three LVDT ("noise") which becomes worse as wind-sway increases. Fritschen *et al.* (1977) tried to overcome noise by guying the tree but this was not entirely satisfactory, as tests with our lysimeter also indicated. The lysimeters described here operate satisfactorily at above-canopy windspeeds of up to 5 m/s. At higher windspeeds noise makes interpretation of the signal difficult, even when integrated over hourly periods.

CALIBRATION

Calibration of each lysimeter is by sequential addition of ten 10-kg weights around the base of the tree while 1-second counts of the sensors' output are recorded. Recording while unloading provides a check on hysteresis.

In Fig. 3 data are presented for calibration of one lysimeter in millimetres of

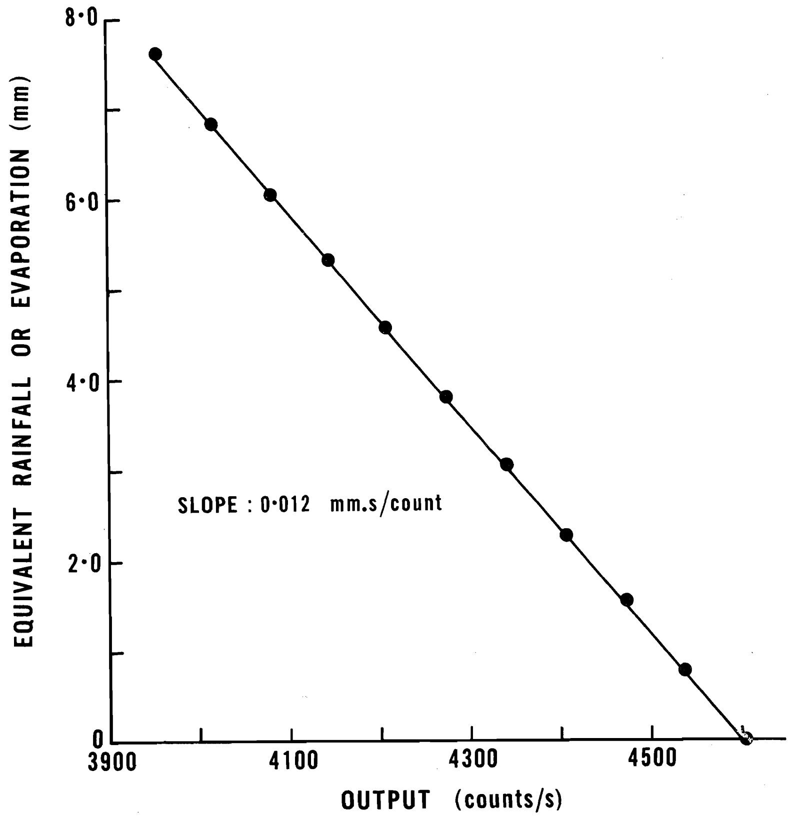

FIG. 3—Calibration of a lysimeter.

evaporation or rainfall against output in counts per second (the ground area occupied by the tree crown was 13.12 m^2). Providing there is no disturbance in the equilibrium adjustment of the beams or the LVDT assemblies, the calibrations are exactly repeatable and the slope of the calibration lines in Fig. 3 has remained constant for at least 1 month. The resolution provided by the lysimeter is the slope of the calibration line which is 0.012 mm.s/count in Fig. 3 – well within that required for measurements of evaporation from individual trees.

The part of the system most likely to be affected by temperature change is the LVDT assembly and accompanying electronics since any temperature effect on the beams and the springs will be cancelled by their arrangement. To test temperature sensitivity the beams on a lysimeter were locked in position and held throughout a day when temperature changed by 15°C. Over this temperature range the apparent weight change was small (0.7 kg, or 0.053 mm) which indicates a temperature sensitivity of only 0.004 mm/°C. Normally a weighing lysimeter is checked by enclosing the vegetation in polythene to remove the confounding effect of transpiration loss because of changes caused by temperature fluctuation. In our system this was not possible. However, calibration over a range of temperatures was constant within the limits previously referred to.

RESULTS

The examples presented here illustrate the applicability of results from the lysimeter to studies of water use by *P. radiata* forest.

Figure 4 shows hourly rates of evaporation from one lysimeter tree when the canopy was fully dry and weather conditions were warm and sunny on 30 January 1982. Rates of evaporation increased rapidly after dawn and reached 0.67 mm/h at midday. During the afternoon rates fell to nearly zero by dusk. This is a good example of transpiration from a well-watered tree in summer conditions. Total water loss from the tree over the day was 5.6 mm. The negative values for evaporation before dawn are the measurement of dew formation. Typically, 0.2–0.5 mm of dew are formed in a night (Rutter 1975) and such quantities are easily resolved by this lysimeter system.

On a dull overcast day on 16 December 1981 the hourly rates of evaporation from the same tree were much lower (Fig. 5), reaching 0.17 mm/h at noon, and total evaporation for the day was 1.6 mm. No dew formation occurred during the early morning.

On 23 January 1982 the day was overcast but fine between 0700 and 1200 h but rain then fell until 1800 h. During the morning there was an evaporative loss from dry foliage (transpiration) of 1.44 mm but between 1200 and 1700 h rainfall exceeded evaporation (Fig. 6). During this time cumulative gross rainfall was 2.8 mm and the difference between cumulative evaporation and gross rainfall measured by the lysimeter was 1.3 mm. The difference between these figures gives the rate of evaporation during rain (interception loss) which is an average of 0.3 mm/h. Transpiration losses are shown as positive values and nett gain in lysimeter weight as negative values in Fig. 6. Rain eased after 1800 h and ceased after 2000 h – the evaporation (i.e., interception loss) would have been almost entirely from wet foliage and may have occurred during or after rainfall.

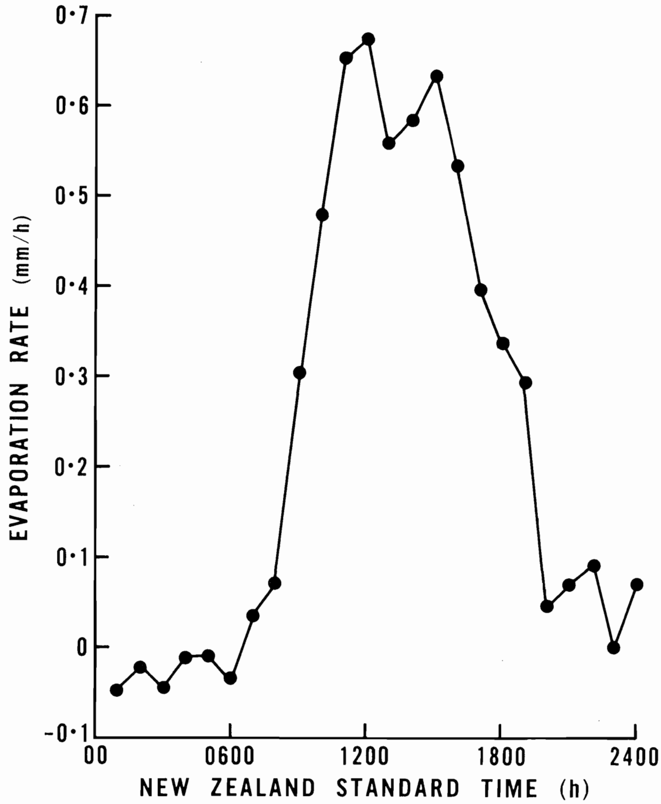

FIG. 4—Hourly rates of evaporation from the dry canopy of a lysimeter tree on a warm, sunny, summer day.

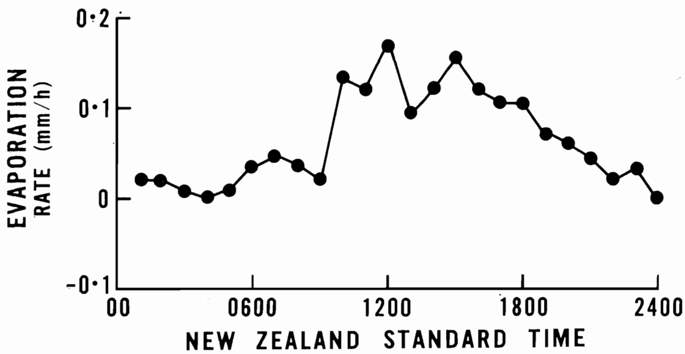

FIG. 5—Hourly rates of evaporation from the dry canopy of a lysimeter tree on a dull, overcast, summer day.

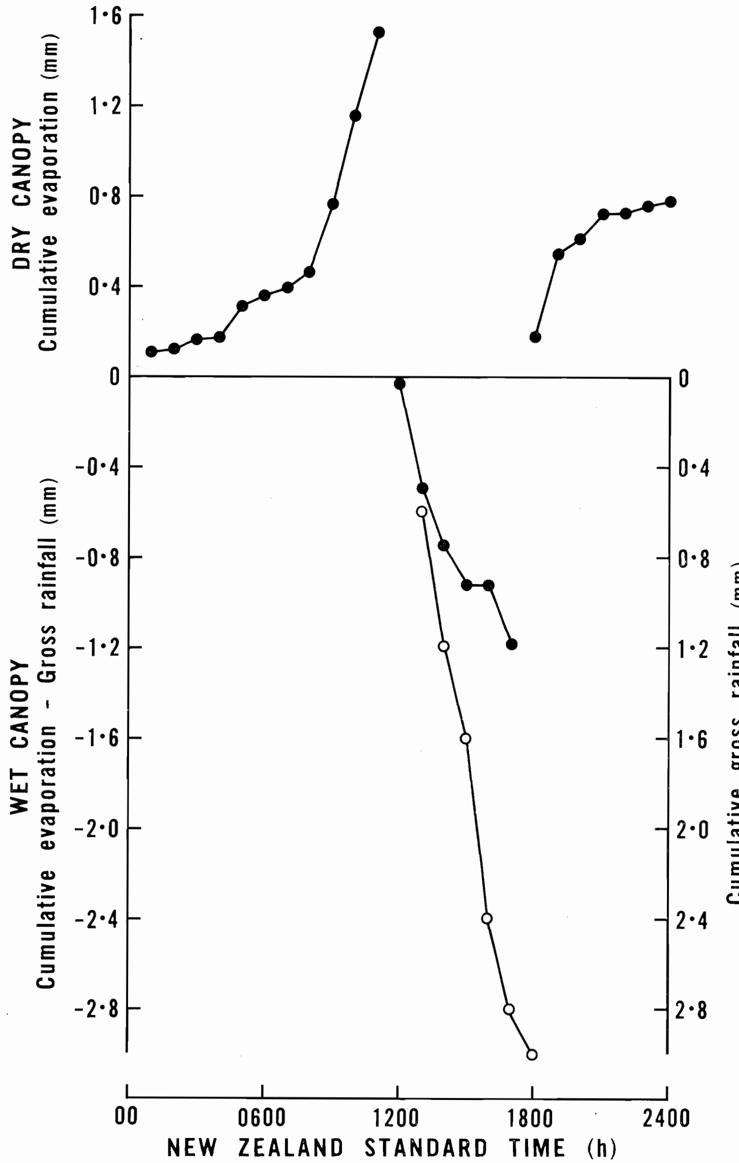

FIG. 6—Cumulative evaporation minus gross rainfall on a summer day during which some rain fell. Evaporation from the dry canopy is shown as positive. When gross rainfall exceeds evaporation the values are negative (o = cumulative gross rainfall; ● = cumulative evaporation minus gross rainfall). From 1800 h there was no further rain and evaporation occurred from the canopy.

Rain fell all day during 24 February 1982 and was particularly heavy during the early morning. A plot of cumulative evaporation minus gross rainfall (Fig. 7) shows decreasing values throughout the day since nett rainfall (including throughfall and stem flow) was always greater than rates of interception from the wet canopy. Cumulative gross rainfall over the whole day was 36.2 mm, and the difference between cumulative evaporation and gross rainfall measured by the lysimeter was 14.9 mm. This gives a difference of 21.3 mm, which is an average rate of interception loss of 0.9 mm/h. This figure is higher than rates of evaporation from dry canopies (cf. Fig. 4 and 5).

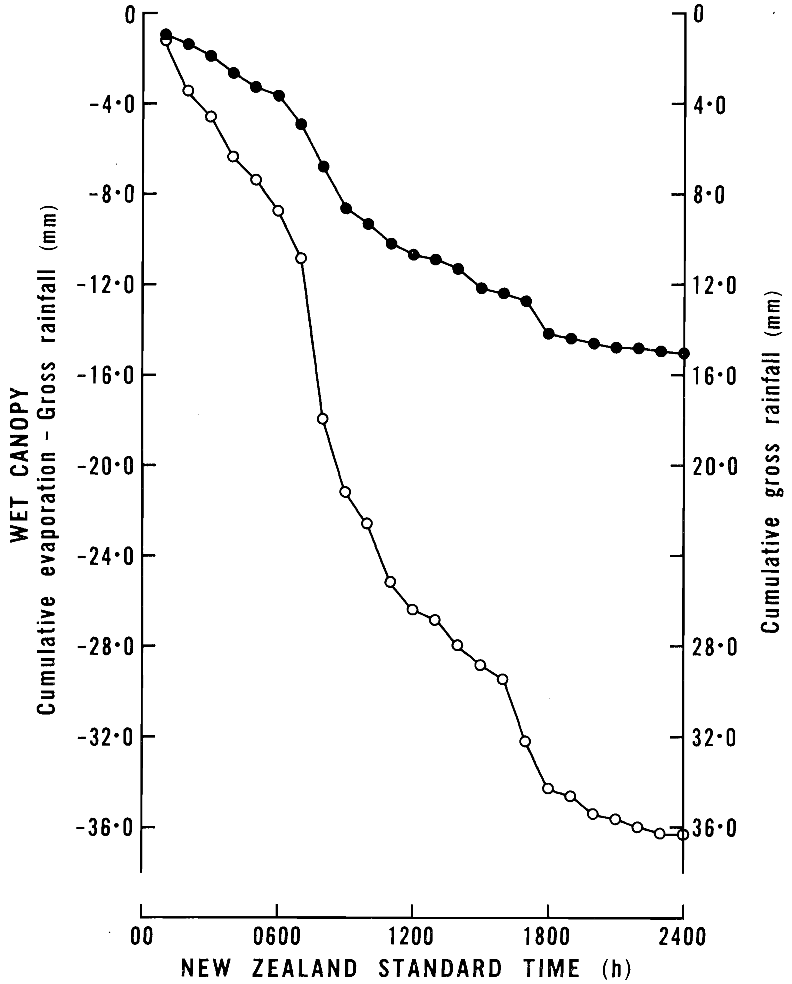

FIG. 7—Cumulative evaporation minus gross rainfall on a summer day when heavy rain fell throughout the day and the canopy was continuously wet (o = gross rainfall; ● = cumulative evaporation minus gross rainfall).

DISCUSSION

The four examples given above demonstrate the use of the lysimeter under a range of weather conditions from dry and sunny to completely wet. Data of this type are being collected over long periods to analyse the processes of water use by a *P. radiata* stand. Together with weather station data they will be used in developing models of evaporation from dry and wet canopies for predicting the effects of stand management on water use by forest. It is intended that at a later stage different treatments will be applied to different lysimeter trees, e.g., fertiliser, pruning, and simulated drought are possibilities. The availability of six replicates offers many advantages and will be exploited for comparison of treatment effects.

The important factors incorporated in this lysimeter design are minimal below-ground construction, simplicity of design and construction (parts are simple and few require machining), minimal maintenance requirement, ready access to all parts, and a simple and reliable calibration procedure. These factors have been significant in developing what we believe is the first reported facility offering six weighing lysimeter units containing large trees.

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