A FIELD LYSIMETER TO STUDY WATER MOVEMENT AND NUTRIENT CONTENT IN A PUMICE SOIL UNDER *PINUS RADIATA* FOREST

I. SITE AND CONSTRUCTION DETAILS

G. M. WILL
Forest Research Institute, New Zealand Forest Service, Rotorua

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ABSTRACT
In 1961 a lysimeter was designed and constructed so that studies could be made of the quantity and chemical content of soil water draining beyond the tree rooting zone in Kaingaroa State Forest. An 8.5-m^2 concrete collection pad was built at a depth of 2.7 m with a pipe leading to an instrument hut 9.6 m away. After the pad had been covered with a plastic sheet, the multi-layered pumice-ash soil profile was replaced and compacted over it and the surrounding excavated area. **Pinus radiata** seedlings were then planted.

INTRODUCTION

From the late 1800s lysimeters have been used to study aspects of water use by plants and water movement in soils. Some have involved major engineering work to provide for the accurate weighing of a unit containing a soil-plant system; others have been no more than simple devices to intercept and collect water percolating through a soil. Kohnke *et al.* (1940) and Makkink (1959) have reviewed the types of lysimeters and their use, and have discussed the limitations that must be recognised in interpreting and applying the results.

For most agricultural crops, isolation of small undisturbed soil-plant units and weighing studies of evapotranspiration are relatively easy, but failure to achieve a complete seal between the soil block and its container have often made the results of soil-percolation and nutrient-leaching studies unreliable. However, today the use of drilling machines that take large-diameter cores and insert them into tight-fitting containers has overcome many of the problems, at least in fine-textured soils (N. Wells, pers. comm.).

The use of lysimeters in studies with forest trees presents considerable problems because of the size and weight of the soil-plant units involved. In some studies a mature tree and the greater part of its root system, complete with soil, have been separated from their surroundings, and then sensitive weighing equipment has been installed to follow rates of water usage (Fritschen *et al.,* 1973). In other studies young

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trees have been planted in containers filled with soil and measurements begun once the trees have grown to a suitable size; this technique is usually practicable only with faster-growing species and when the study is of water use by the tree and not water or nutrient movement in the soil. For the latter, disturbance of the natural soil structure can have large effects on the results obtained (Colman and Hamilton, 1947; Minderman and Leaflang, 1968).

To avoid soil disturbance "open pan" lysimeters have been installed by horizontal tunnelling from a vertical pit or shaft. These have yielded valuable data on the composition of percolating water but with uncertainty as to how accurately the rate of collection was a measure of the rate of water flow through the soil. Disruption of the soil-water column and an inadequate seal between the lysimeter and the soil under-surface can both lead to underestimates of the flow (Cole, 1958).

Tension plate lysimeters have been developed to provide natural continuity between the soil-water column and the collection plate; these have provided valuable data in many studies (Cole, 1958; Cole *et al.*, 1961).

Large areas of *Pinus radiata* D. Don have been planted on the pumice soils of the central plateau of the North Island of New Zealand. Tree growth rates are high and estimates have been made of dry matter production and nutrient cycling within the tree-soil system (Will, 1968). Because of the high productivity, larger-than-usual quantities of nutrients are removed from the site in forest produce. Little is known, however, about the loss of nutrients in drainage water and its chemical quality. Furthermore, it is not known when soil drainage takes place and whether its volume is related to annual and seasonal variations in the rainfall. To obtain base line data on soil water draining beyond the tree rooting zone, a non-weighing lysimeter was installed in Compartment 69, Kaingaroa Forest, in 1961.

This paper describes the construction of the lysimeter; because of the coarse nature of the soil and lack of soil structure in any of its layers, it was considered that a reconstituted soil profile could be used. The rapid growth rate of *P. radiata* meant that, starting with tree seedlings, closed canopy forest conditions could be reached in about 5 years. To allow normal root patterns to develop it was decided to construct a collection base deep within the soil rather than to construct a totally enclosed container. It was realised that this would allow the possibility of lateral water movement above the collection base but it was thought that with careful replacing of the soil layers this movement should be small. Any disadvantages would be outweighed by the freedom provided for root systems to develop naturally, especially after thinnings later in the life of the tree crop.

Patric (1961) has described large containers set in the ground at San Dimas in these words: "lysimeters are a poor place for raising trees". It was hoped that the design adopted would be an improvement on those used in previous studies.

SITE DESCRIPTION

Soils

In the central region of the North Island extensive areas (300 000 ha) of *P. radiata* plantations have been established on pumice soils that have formed on rhyolitic pumice ash deposits from several volcanic centres. The largest of these forests is Kaingaroa

Forest which covers much of the relatively flat surface of the Kaingaroa plateau at an elevation of 500-800 m (Fig. 1).

The statigraphy and chronology of the ash deposits have been described by Healy *et al.* (1964) and Vucetich and Pullar (1973). The pumice deposits form a mantle several metres thick over ignimbrite rock which is weathered and fissured, presenting no real barrier to seepage water.

Compartment 69 of Kaingaroa Forest occupies a central position within the forest and the yellow-brown pumice soil (Kaingaroa silty sand) is typical of that found over

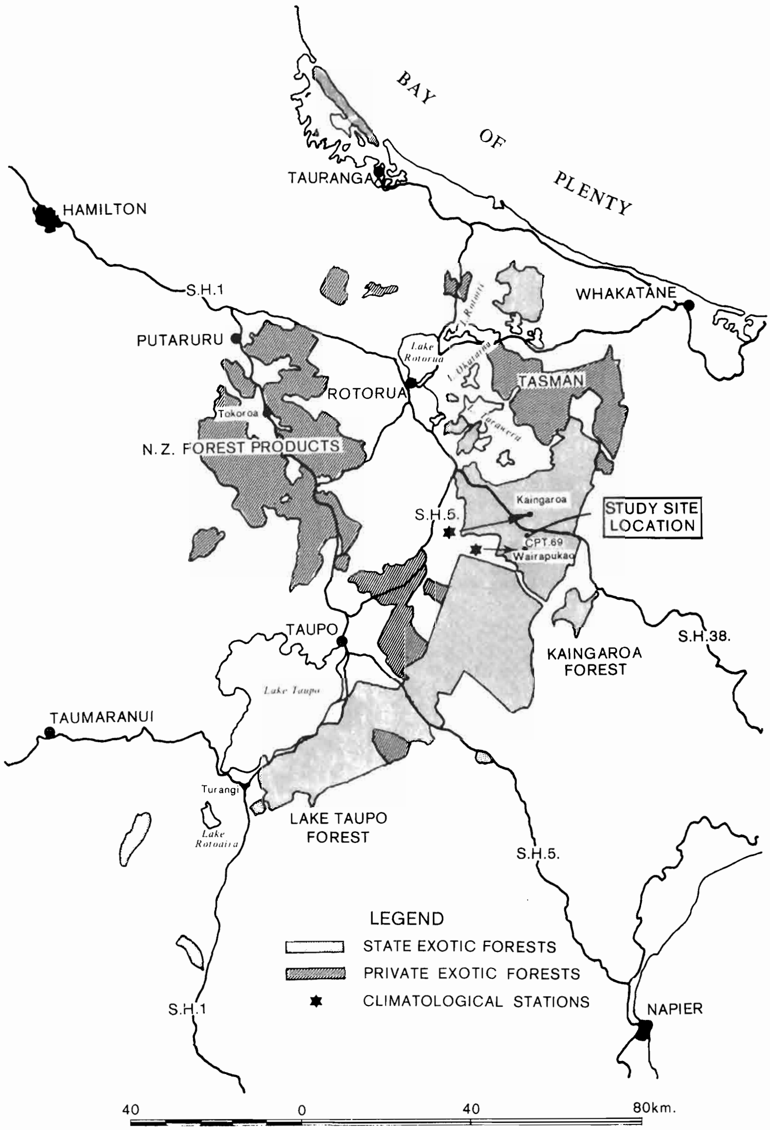

FIG. 1—Location of principal exotic forests on pumice soils of central North Island, New Zealand.

thousands of hectares of the surrounding area (Vucetich, 1960). Several hectares of the compartment have been set aside for studies of the soil and tree growth. At the study site the soil profile consists of the volcanic ash formations shown in Fig. 2. A 5-cm thick loamy sand topsoil has developed on the surface sandy pumice ash layer which is about 50 cm thick. This rests on a 60-cm layer of pumice gravel underlain by a succession of paleosols developed on ash layers which range from gravelly sand to silty sand. The volcanic ash mantle over the ignimbrite rock has a thickness of 3.4 m. Full details are given by Pullar (1968).

Will and Knight (1968) have examined the nutrient status of the six major ash layers, to a depth of about 2.6 m, by means of glasshouse pot trials using an intensive cropping technique. The soil chemistry of the same layers has been reported on by Knight and Will (1970). Will and Stone (1967) studied the moisture storage of the soil and estimated that at field capacity it contains about 900 mm of plant-available moisture in the top 3 m. After comparing data from other sites some 50 km apart they concluded that, over many thousands of hectares around the experimental site, trees have access to at least 760 mm of stored rain after the winter recharge of the profile. This relatively high storage results from the large internal pore space characteristic of pumice particles and the ability of tree roots to penetrate to the full depth of the soil profile.

Climate

The experimental site lies between two official climatological stations (Fig. 1); Wairapukao (B86551) 4 km to the south, and Kaingaroa (B86451) 9 km to the north. Rainfall data for many years are available from both stations. Annual rainfall normals (1941-70) are 1413 mm and 1549 mm for the two stations (Anon., 1973a; 1973b). On average, rainfall is fairly evenly distributed throughout the year. Mean monthly rainfall at Wairapukao (1941-70) is 118 ± 13 mm. The driest month is March, with slightly higher-than-average rainfall in the autumn/winter months May to August. The average number of rain days is 130 days/yr. Rainless periods of 2-4 weeks are not uncommon in summer and cause droughts in grassland. Particularly during winter rainstorms, rainfall intensity can be high with falls of 50-80 mm/h not uncommon. Snow and hail seldom occur.

The mean annual temperature at Wairapukao for the period 1931-60 was 10.7°C (Anon, 1973b). Ground frosts occur an average 124 days/yr.

The nearest stations recording sunshine hours are Taupo to the south-west and Rotorua to the north-west. Annual averages at these two locations are 2037 and 1972 hours respectively; at the study site sunshine is probably about 2000 h/yr, or about 47% of possible hours.

Silvicultural History

The first crop of *P. radiata* was planted in Cpt 69 by drill-sowing in 1927; it was clearfelled between September 1957 and March 1958. This was followed by natural regeneration. Prior to forest establishment the native vegetation had consisted primarily of *Leptospermum scoparium* J.R. et G.Forst. and *Dracophyllum* spp.

CONSTRUCTION METHODS AND DETAILS

In 1961 near the south margin of Cpt 69 a bulldozer was used to dig a trench 4 m wide and 4 m deep at its deepest point; all the spoil was dumped beyond one end of

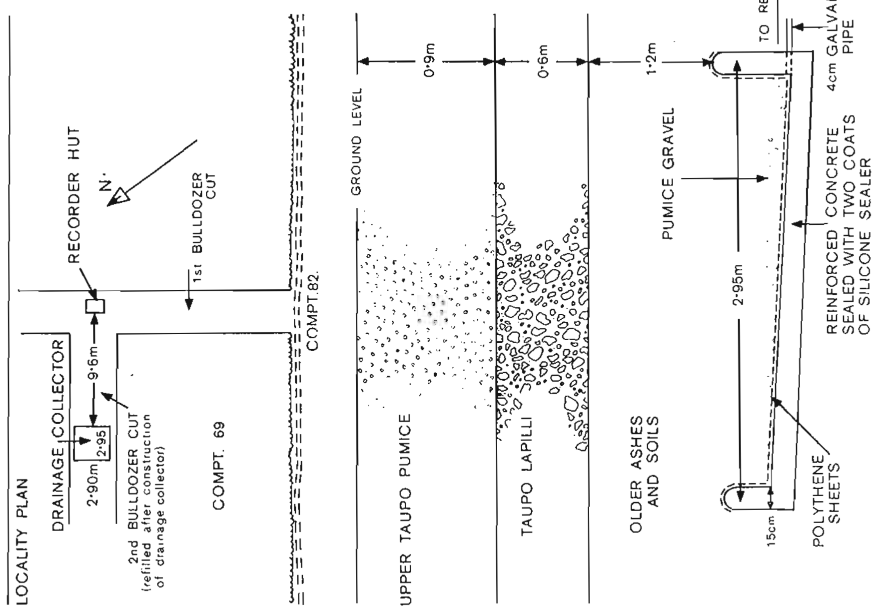

FIG. 3—Locality plan and side elevation of lysimeter, Compartment 69, Kaingaroa Forest.

From top of profile: T.a. Taupo Ash topsoil; T.r. Taupo Rhyolite block member; T.l. Taupo Lapilli; R.s. Rotongaio Sands; W.p. Waimihia Paleosol; R.p. Rotoma Paleosol.

FIG. 2—Soil profile, Compartment 69, Kaingaroa Forest. (Spade height = 1 m).

the trench. A second trench was cut at right angles to the first, joining it at its deepest point (Fig. 3). On the floor of the second trench a concrete base, approximately 2.90 m × 2.95 m, was laid with a sloping floor, a low surrounding wall, and a pipe which led to the first trench. Full details are given in Fig. 3 and in Fig. 4 where the completed base is shown.

After the pad had been sealed with silicone sealer, covered with a sheet of polythene, and had a layer of coarse pumice laid across it, the soil profile was replaced in the whole of the second trench (Fig. 3). Some of the replaced soil came from the trench but, because of mixing, a large amount was unsuitable; additional material was "mined" from one end of the first trench. The individual layers were replaced in position and compacted largely with the aid of wheelbarrows and trampling. The degree of compaction achieved, although probably not as great as originally present, has been sufficient to prevent any subsequent settling of the soil. *Pinus radiata* seedlings were then planted at 2 m × 2 m spacing over the trench and in the surrounding area. Four marker posts were placed above the corners of the lysimeter pad.

Where the outflow pipe ended in the first trench, which was left open, a small hut was built to house recording and collection apparatus.

FIG. 4—Lysimeter collection pad and drainage pipe at base of excavated trench before replacement of soil profile.

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