RAINFALL INTERCEPTION BY MOUNTAIN BEECH

L. K. ROWE

Protection Forestry Division, Forest Research Institute, Rangiora

(Received for publication 11 September 1974)

ABSTRACT

A study of rainfall interception by mountain beech forest was carried out in the Craigieburn Range, Canterbury, for 6 summers. Of the gross rainfall, 60.1% was recorded as throughfall, 1.3% as stemflow and 38.6% as interception loss. High rates of evaporation from interception storage were inferred. Significant linear relationships were determined for gross rainfall and throughfall, and for interception loss. No significant differences could be detected between sites or years for these relationships. Loss of rainfall back into the atmosphere was about 250 to 275 mm for the period November to May.

INTRODUCTION

During the summer of 1965-66, a study of rainfall interception by mountain beech forest (*Nothofagus solandri* var. *cliffortioides*) was begun by Dr H. M. Keller of the Swiss Forest Research Institute. Measurements were continued after Dr Keller's departure from New Zealand in 1967 until the end of the summer 1970-71.

The work was done on two plots in Camp Stream, an International Hydrological Decade Experimental Basin situated in the New Zealand Forest Service research area in the headwaters of Broken River, Craigieburn Range, Canterbury (Fig. 1). A general description of the geology, vegetation and climate of the Broken River area can be found in Morris (1965). The average annual precipitation at the study sites is about 1750 mm. The greater part of the precipitation falls as rain from about November to May, but there is a substantial proportion as snow during the rest of the year. This work was confined to the study of rainfall interception during the snow- and frost-free part of the year.

The forest at both sites is pure, single-storeyed mountain beech on about 30° slopes. The trees range in form from saplings less than 10 cm diameter at breast height (d.b.h.) to overmature trees greater than 60 cm d.b.h. Litter interception was ignored as there is only a very shallow layer present, about 1-2 cm deep. Table 1 gives some stand characteristics for the study plots which were about 40 m from the forest edge.

The frequency distribution of tree sizes, based on d.b.h. measurements, was not significantly different between plots ($\chi^2_{d.f.=8} = 9.90$, $p > 0.05$). The apparent differences in Table 1 reflect a slightly greater number of very large trees on plot 2.

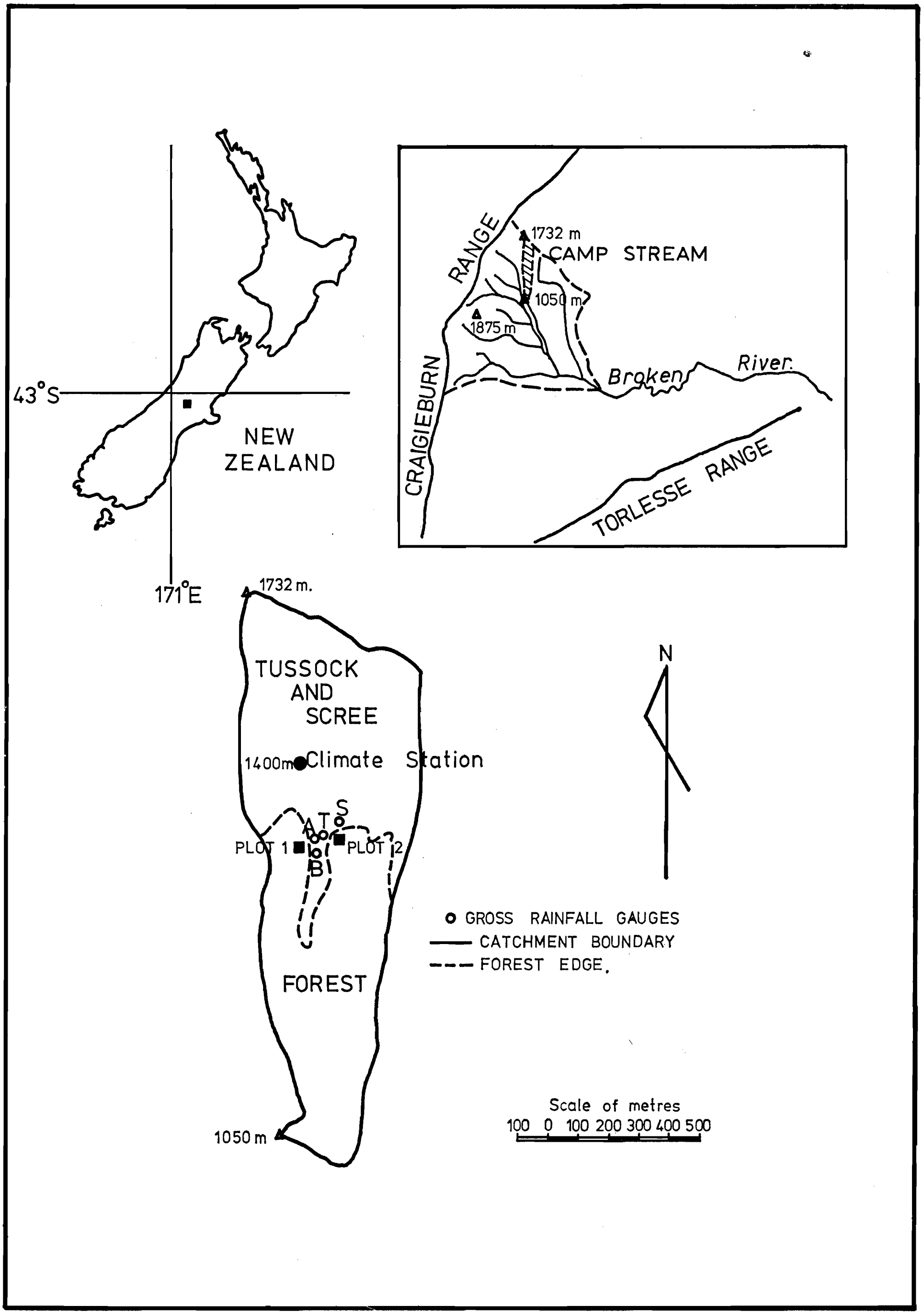

FIG. 1—Location maps showing Camp Stream interception plots.

TABLE 1 - Stand characteristics of study plots

Plot	Altitude m a.s.l.	Aspect	Tree height m	Density stems/ha	Basal Area m^2/ha	Mean d.b.h. m
1	1220	SE	12	1500	55	0.193
2	1250	WSW	12	1400	70	0.223

TERMINOLOGY

There is considerable confusion in the literature on the terminology used in interception studies (Helvey & Patric, 1965a; Zinke, 1967). The following definitions follow those given by Hamilton & Rowe (1949) and are now commonly used.

Gross rainfall (P): the rainfall falling on to the canopy.

Throughfall (T): the portion of gross rainfall reaching the ground either directly through canopy spaces or as drip from the vegetation.

Stemflow (S): the portion of gross rainfall reaching the ground by flowing down the stems.

Net rainfall (R): the portion of gross rainfall reaching the ground, i.e., the sum of throughfall and stemflow.

Interception loss (IL): the portion of gross rainfall retained by the vegetation and evaporated directly into the atmosphere. This is equal to the difference between gross rainfall and net rainfall.

Other definitions are given in Zinke (1967).

EXPERIMENTAL METHODS

Sampling usually began about the beginning of December and finished when snow or freezing made measurements impossible—about May. Records were taken at site 1 for the summers of 1965-66 and 1966-67 and at site 2 for the remainder of the study. Because only one plot was used and this was relocated after 2 years, statistical procedures for comparing sites were not completely satisfactory; however comparison of regression tests (Freese, 1967) were possible. If a number of randomly located sample plots had been used for the whole of the study period a comprehensive analysis of variance would have been applicable. All measurements refer to ground slope areas.

Gross rainfall was estimated as the mean of two raingauges located just outside the forest edge near the appropriate study plot; A & B for plot 1, S & T for plot 2—*see* Fig. 1. Only one of the gauges had the same ground slope and aspect as the corresponding throughfall plot, important criteria when siting gross rainfall gauges (Helvey & Patric, 1965b). Sometimes very large differences between the two gauges, probably caused by the differing aspects of the gauges and the degree of exposure relative to wind direction as well as interception of rainfall by the forest canopy edge, made estimates unreliable. The use of more gross rainfall gauges, possibly some at canopy level, would have increased the reliability of the rainfall estimates. The problems of canopy level sampling have been discussed by Helvey & Patric (1965a), Law (1957) and Reynolds & Leyton (1963).

Throughfall was measured using a grid of 100 points (Fig. 3) to randomly locate 15 raingauges 127 mm in diameter. At site 1, readings were taken every fortnight and the gauges relocated. Readings were taken at site 2 (Fig. 2) after all significant storms or when the gauges were relocated, about every 2 weeks.

Limited data were available from a 2.50 × 1.00-m trough with a Lea water level recorder attached to the collecting drum. The weekly time scale was too small for interpolating within 1 h and the recording raingauge at the climate station was too far away and too insensitive for accurate time comparisons to be made.

To measure stemflow, a lead collar approximately 10 mm wide was sealed to the trunk of every tree in one subplot, 15.24 × 6.10 m, within each of the throughfall plots.

FIG. 2—Interception plot at site 2—throughfall gauge in foreground; stemflow plot in middle centre to right; throughfall trough and recorder in left background.

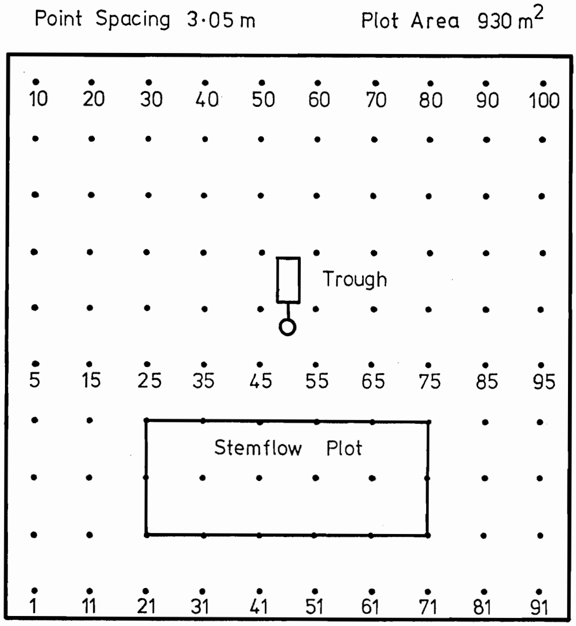

FIG. 3—Throughfall plot layout.

The collected water from each tree was led off into individual 4.5-l plastic bottles (Fig. 2). Measurements were made at the same time as throughfall, with additional readings during heavy storms to minimise overflows. Replicated plots could have added valuable data to the results.

RESULTS AND DISCUSSION

Few studies have been published on the interception of rainfall by *Nothofagus* species: Aldridge & Jackson (1973) and Miller (1963) for hard beech, *N. truncata,* near Wellington, New Zealand; Ovington (1954) for *N. obliqua,* a deciduous South American species, in England. Other overseas results can be found for a related genus, *Fagus,* also deciduous.

Throughfall

A summary of the seasonal results is given in Table 2. Although there was considerable variation in the amount of gross rainfall sampled from year to year, the percentage recorded as throughfall remained reasonably constant, ranging from 58.0% to 64.3%. At an average of 60%, throughfall under mountain beech was considerably higher than the 45% for hard beech measured by Aldridge & Jackson (1973) and at the higher end of the range 50-60% recorded by Miller (1963) for the same species. This throughfall, however, was smaller than that reported by Ovington (1954) for *N. obliqua,* 67-71%, and for *Fagus* species in general: 76%, Aussenac (1968); 75.8%, Eidmann (1959); 82-87%, Leonard (1961); 70-80%, Nihlgard (1969); 73% Noirfalise (1959); 85.9%, Sheng & Koh (1967). Throughfall measured for other broadleaf species is commonly in the range 70-90%, although Jackson & Aldridge (1973) measured 47.8% under kamahi (*Weinmannia racemosa*), also at Taita.

TABLE 2 - Summary of seasonal (summer/autumn) interception results

Year	Period	Gross Rainfall	Throughfall		Stemflow		Interception loss	
		mm	mm	%	mm	%	mm	%
1965-66	16.2.66 -17.5.66	274	176	64.3	2	0.7	96	35.0
1966-67	12.10.66-29.3.67	710	412	58.0	6	0.9	292	41.1
1968-69	10.12.68- 2.6.69	561	329	58.6	8	1.4	224	40.0
1969-70	26.11.69- 3.5.70	652	387	59.4	10	1.5	255	39.1
1970-71	1.12.70-14.6.71	641	403	62.9	10*	1.5	228	36.6
Total		2838	1707	60.1	36	1.3	1095	38.6

* Estimated

Point throughfall under mountain beech was highly variable, the degree being reflected by the large coefficients of variation found for each measurement period. Only nine of the 110 storms sampled had coefficients of variation less than 25%. The median value was 38% and 22 storms were in the range 50-85%. Fortnightly samples were slightly better, the corresponding figures for 19 periods being 8, 28%, and 5 for periods with coefficients of variation less than 25%, median coefficient and periods with coefficients of variation in the range 50-85%, respectively.

One extreme drip point is often the cause of the very high coefficients of variation calculated. For example, the removal of a high drip point from two fortnightly samples reduced the coefficients of variation of 85% and 80% to 35% and 21%, respectively. A similar effect was noted for storm samples. Many throughfall samples for smaller storms also had large coefficients of variation, e.g., six storms with gross rainfall less than 3 mm had coefficients greater than 60%. Although Helvey & Patric (1965b) concluded that roving cylindrical gauges were preferable, sufficient large trough gauges may have given a more accurate assessment of the highly variable throughfall found under mountain beech forest.

Linear regression analysis was used to determine relationships between gross rainfall and throughfall on both the storm and fortnightly bases. The resulting equations are given in Table 3 and the data used with the appropriate overall equations are shown in Figs. 4 and 5. All equations gave highly significant regression coefficients despite inadequate sampling and the highly variable data. The large 95% confidence limits for the regression coefficients reflect the scatter of the data points about the regression lines, limiting their usefulness as prediction equations. No significant differences could be detected between seasons at a given site, or between sites in the case of the fortnightly data grouped for all seasons.

TABLE 3 - Throughfall-gross rainfall relationships

fortnightly samples

Period	Equation	F	n
1965-66	$T = -(1.9 \pm 14.1) + (0.68 \pm 0.25)\ P$	56**	6
1966-67	$T = -(1.0 \pm 11.2) + (0.60 \pm 0.16)\ P$	67**	12
1965-67	$T = -(0.9 \pm 7.6) + (0.61 \pm 0.12)\ P$	123**	18
1968-69	$T = -(4.9 \pm 6.1) + (0.70 \pm 0.13)\ P$	150**	13
1969-70	$T = -(2.3 \pm 9.2) + (0.63 \pm 0.13)\ P$	129**	11
1970-71	$T = -(7.4 \pm 10.8) + (0.78 \pm 0.18)\ P$	97**	12
1968-71	$T = -(4.1 \pm 4.5) + (0.69 \pm 0.07)\ P$	363**	36
1965-71	$T = -(3.0 \pm 3.8) + (0.66 \pm 0.06)\ P$	485**	54

storm samples

Period	Equation	F	n
1968-69	$T = -(1.4 \pm 1.3) + (0.68 \pm 0.06)\ P$	627**	36
1969-70	$T = -(2.0 \pm 2.7) + (0.67 \pm 0.07)\ P$	384**	25
1970-71	$T = -(3.2 \pm 3.0) + (0.77 \pm 0.11)\ P$	247**	27
1968-71	$T = -(1.9 \pm 1.2) + (0.69 \pm 0.04)\ P$	1205**	88

Confidence limits at 95% level

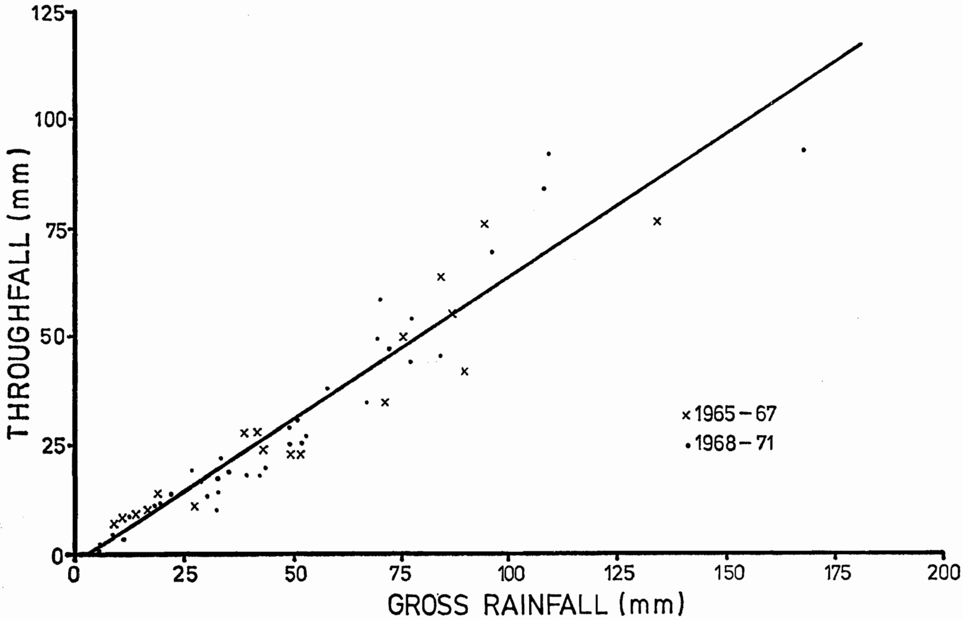

FIG. 4—Throughfall-gross rainfall relationship for fortnightly sampling.

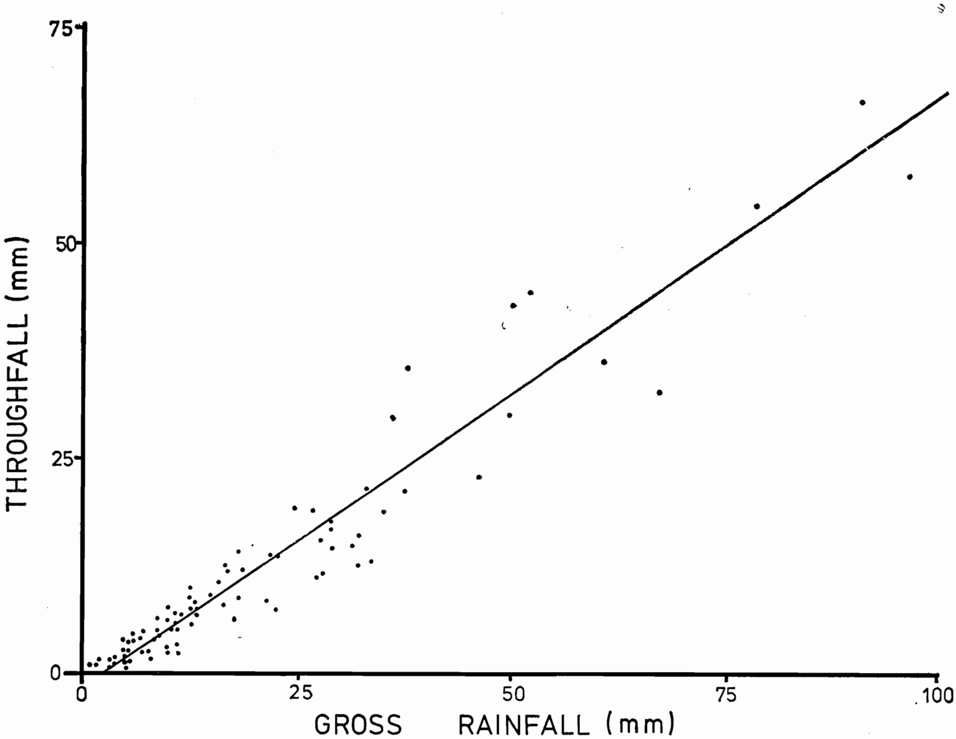

FIG. 5—Throughfall-gross rainfall relationship for storm sampling.

Figs. 6 and 7 show scattergrams relating percentage throughfall to gross rainfall for fortnightly and storm periods. Although the points show a very large scatter, Olmstead and Tukey's corner test for association (Sokal & Rohlf, 1969) does

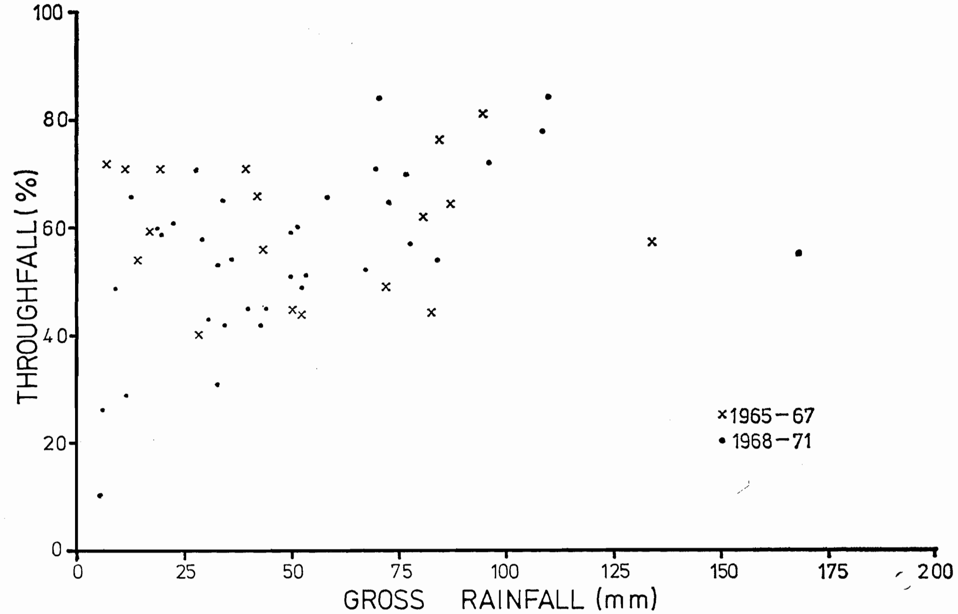

FIG. 6—Percentage throughfall-gross rainfall relationship for fortnightly sampling.

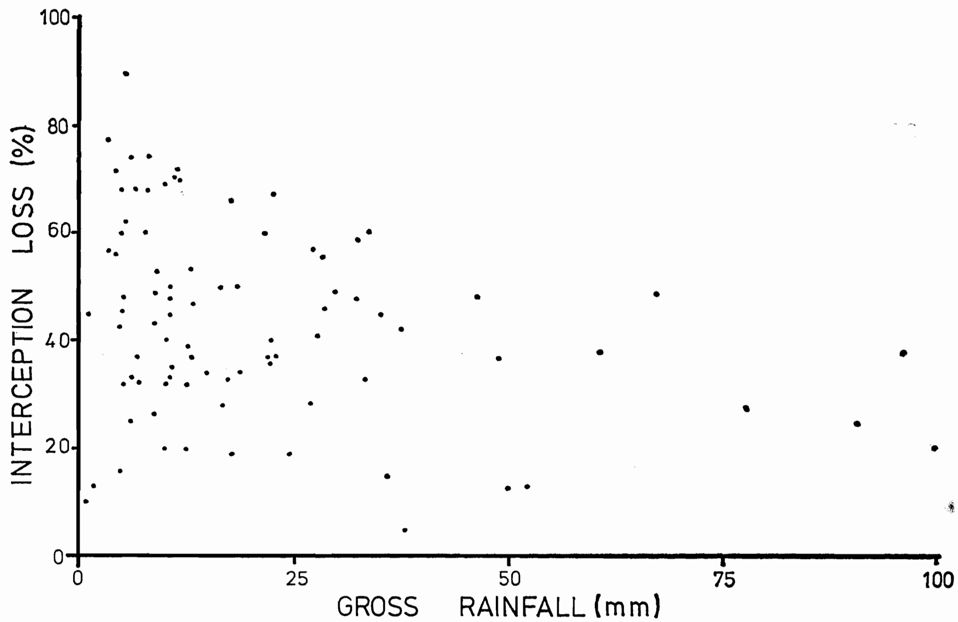

FIG. 7—Percentage throughfall-gross rainfall relationship for storm sampling.

indicate a significant degree of association. Throughfall ranged from 10% to 90% of gross rainfall for each measurement period on both sampling bases.

Stemflow

Stemflow, measured as 1.3% of gross rainfall (Table 2), appears to be low. Only Ovington (1954) gives a lower value for stemflow from a beech stand (0.12% for a single storm of 13 mm gross rainfall). Aldridge & Jackson (1973) measured 15.4% from hard beech, a result at the high end of the range reported in overseas literature. Most studies for *Fagus* stands give values in the range 2% (Noirfalise, 1959) to 16.6% (Eidmann, 1959), the majority being under 10%.

Almost twice as much stemflow was measured at site 2 as at site 1. However, as stemflow was so small, such differences are probably not significant.

Stemflow was estimated to equal or exceed 1 mm during only 10 of the 42 fortnights sampled. The maximum stemflow estimated for any period was about 2 mm. Fig. 8 shows the relationship between stemflow and storm gross rainfall. Because of overflows, estimates only were available for storms greater than about 35 mm gross rainfall. No regression equations are presented because of the wide scatter of points and possible bias of the estimated stemflow for larger storms.

Only six of 61 individual storms at site 2 had estimated stemflow of 1 mm or greater, the highest being of the order of 2 mm.

It has been shown that there are large drip concentrations near the tree trunk caused by water either falling from drip points on the tree stem (Voight, 1960; Voight & Zwolinski, 1964) or falling from branches close to where they join the stem (Bell & Gatenby, 1969; Leonard, 1961; Rutter, 1963). These drip concentrations are usually not measured by throughfall gauges or stemflow collars, causing net rainfall to be underestimated and interception loss to be overestimated. The size of these drip concentrations has been demonstrated by Voight (1960) who found that of water applied to the trunk of a red pine in fine weather, over 50% more was collected in a

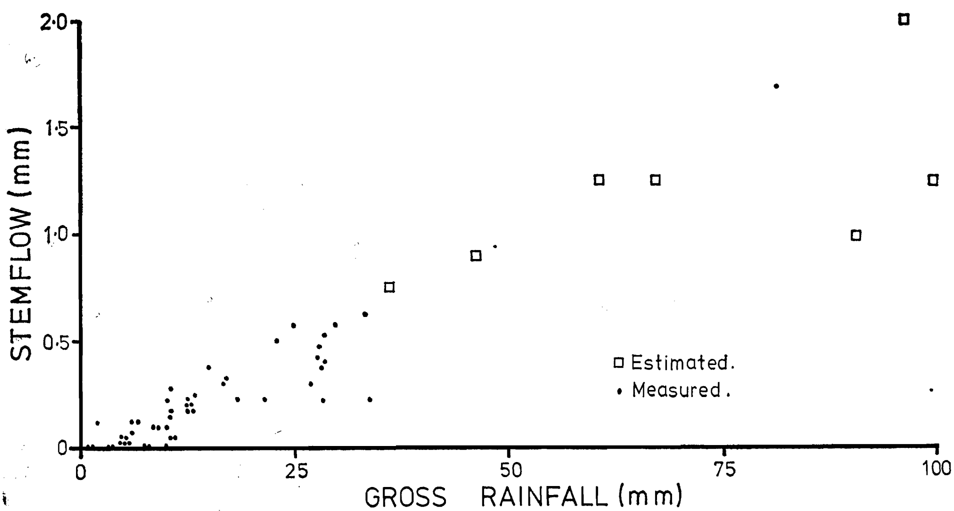

FIG. 8—Stemflow-gross rainfall relationship for storm sampling.

collar 48.3 cm wide than in one 2.5 cm wide. The mountain beech trees in the study plots were covered with a considerable quantity of lichens and mosses (Fig. 2) and mature trees have a very thick and rough-textured bark. These features would provide ample drip points to divert stemflow away from the collecting collars and also would markedly increase the storage capacity of the stems.

Attempts were made to establish linear relationships between stemflow for a given tree and storm gross rainfall. Although significant regression coefficients were obtained for all but two equations, there were inconsistencies between seasons. Some trees showed no differences between seasons, others were significantly different and others could not be compared as the variances of the two groups were not homogeneous (Freese, 1967). No consistent series of relationships could be found relating stemflow for individual trees during a given storm to tree characteristics such as d.b.h., $(\text{d.b.h.})^2$ representing tree stem area, the estimated crown area of the tree, etc. The degree of bark thickness and texture, lichen and moss cover, crown size and density, and branching habit, are extremely variable from tree to tree. Therefore, as the dominant features governing stemflow probably vary from tree to tree stemflow results could have been pooled by collection at one point, instead of recording individual trees separately.

Interception loss

Interception loss was 38.6% of gross rainfall (Table 2) and averaged about 250 to 275 mm for the period November through to May. Aldridge & Jackson (1973) found a similar percentage interception loss for hard beech. This is very much higher than has been reported for *Fagus* species for which results range from 5% (Nihlgard, 1969) to 25% (Noirfalise, 1959). Other broadleaf species may range up to 38% as for sal (Dabral & Subba Rao, 1969) although the majority are below 20%.

Analysis of interception loss-gross rainfall relationships gave similar results to those for throughfall and gross rainfall. As interception loss is virtually the complement of throughfall because of the small measured stemflow, this result was expected. Figs. 9 and 10 show the linear relationship between gross rainfall and interception loss, the

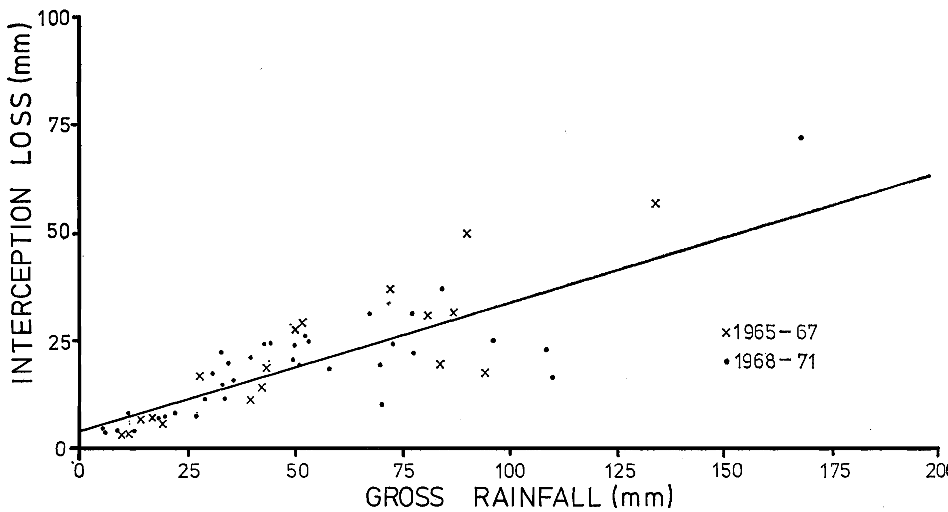

FIG. 9—Interception loss-gross rainfall relationship for fortnightly sampling.

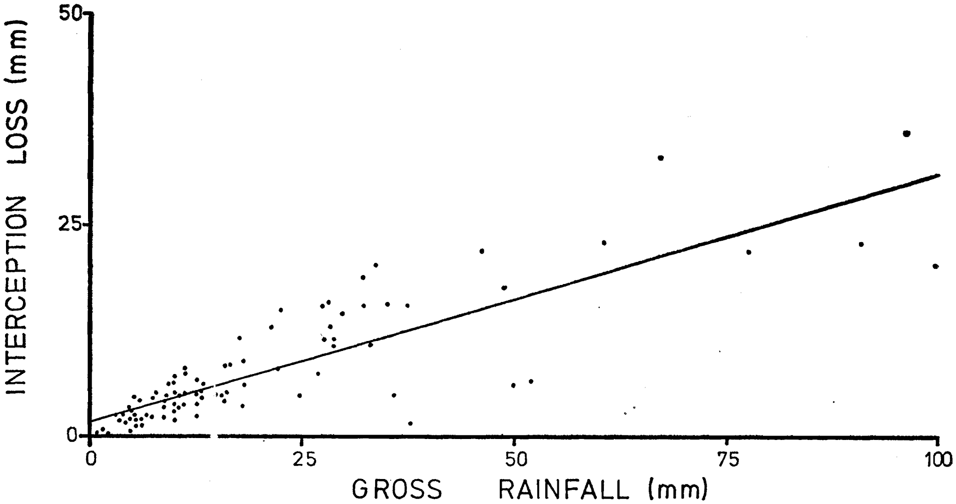

FIG. 10—Interception loss-gross rainfall relationship for storm sampling.

regression equations for which are given in Table 4. All regression coefficients were statistically significant and there were no differences between years or sites. The confidence limits of the regression coefficients were of the same absolute magnitude as for throughfall but were proportionately larger as interception loss was smaller. The equations are of limited use as prediction equations. Scattergrams relating percentage interception loss to gross rainfall showed a significant degree of association (Figs. 11 and 12). Interception loss ranged from about 10% to 90% of gross rainfall for both storm and fortnightly periods.

Interception storage capacity or canopy saturation values may not be referred to directly but are implied, i.e., no throughfall was measured before a given amount of rain fell. Most hardwood studies report values up to 2 mm (Aussenac, 1968; Bell & Gatenby, 1969; De Walle & Paulsell, 1969; Zinke, 1967). For hard beech at Taita, Aldridge & Jackson (1973) implied a value of 1 mm. Interception storage capacity for mountain beech was determined by extrapolating the storm throughfall-gross rainfall relationship to T = O giving 2.7 ± 1.8 mm, the limits of the regression equations defining the range. All four storms with gross rainfall less than 2.7 mm had measureable throughfall. Because of the small leaf size and relatively open nature of the canopy it is probable that considerable throughfall will occur before the canopy is saturated.

Table 5 gives some details of interception losses for storms with gross rainfall over 25 mm. The maximum loss for a single storm was 36.6 mm for a storm lasting 48 hours. The total storm duration and the duration of falling rain were taken off the charts from the throughfall trough recorder. Many of the losses were exceptional and are difficult to reconcile with the relatively short storm durations when the rates of evaporation of intercepted water found by other investigators are considered. Law (1957) has measured interception losses as high as 7.1 mm/day for Sitka spruce. For a Scots pine stand, Rutter (1963) has found that interception storage of 1.6-1.8 mm has evaporated

TABLE 4 - Interception loss-gross rainfall relationships

fortnightly samples

Period	Equation	F	n
1965-66	IL = (2.1 ± 13.2) + (0.31 ± 0.24) P	11*	6
1966-67	IL = (1.0 ± 11.2) + (0.40 ± 0.16) P	29**	12
1965-67	IL = (1.0 ± 7.6) + (0.38 ± 0.12) P	43**	18
1968-69	IL = (5.0 ± 6.1) + (0.28 ± 0.13) P	25**	13
1969-70	IL = (2.5 ± 9.1) + (0.35 ± 0.12) P	41**	11
1970-71	IL = (7.3 ± 10.7) + (0.20 ± 0.17) P	6*	12
1968-71	IL = (4.2 ± 4.4) + (0.30 ± 0.07) P	69**	36
1965-71	IL = (3.1 ± 3.8) + (0.32 ± 0.06) P	117**	54

storm samples

Period	Equation	F	n
1968-69	IL = (1.4 ± 1.2) + (0.31 ± 0.05) P	133**	36
1969-70	IL = (2.1 ± 2.6) + (0.31 ± 0.07) P	85**	25
1970-71	IL = (3.2 ± 3.0) + (0.22 ± 0.10) P	20**	27
1968-71	IL = (1.9 ± 1.2) + (0.29 ± 0.04) P	217**	88

Confidence limits at 95% level

in several hours in summer months. Subsequently, Rutter (1967) has shown, from theory and observations, rates of evaporation of intercepted water can be as high as 7-10 mm/day, i.e., 0.3-0.4 mm/h.

Using Rutter's (1967) results as a guide, evaporation from storage during dry

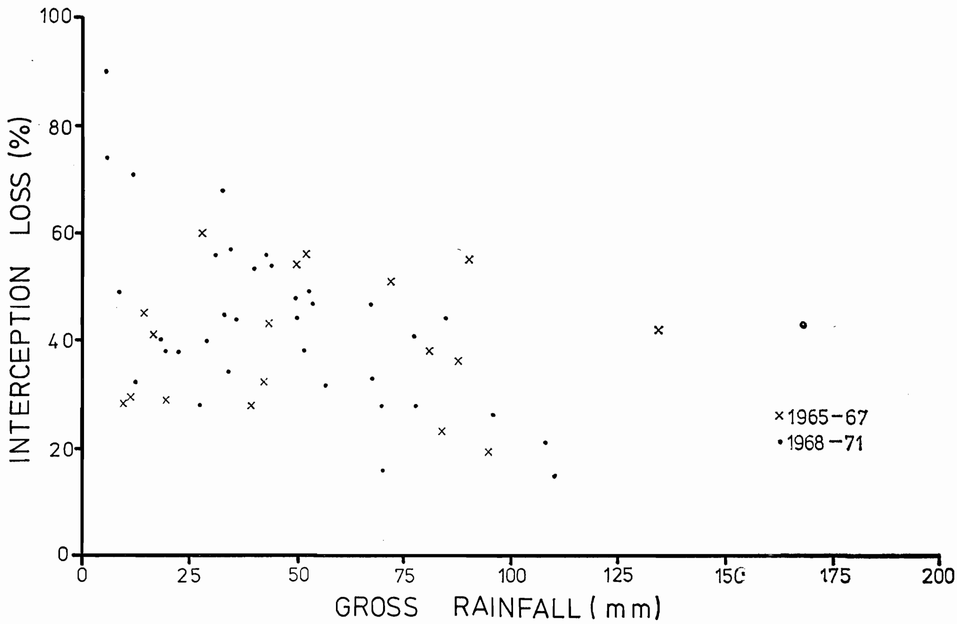

FIG. 11—Percentage interception loss-gross rainfall relationship for fortnightly sampling.

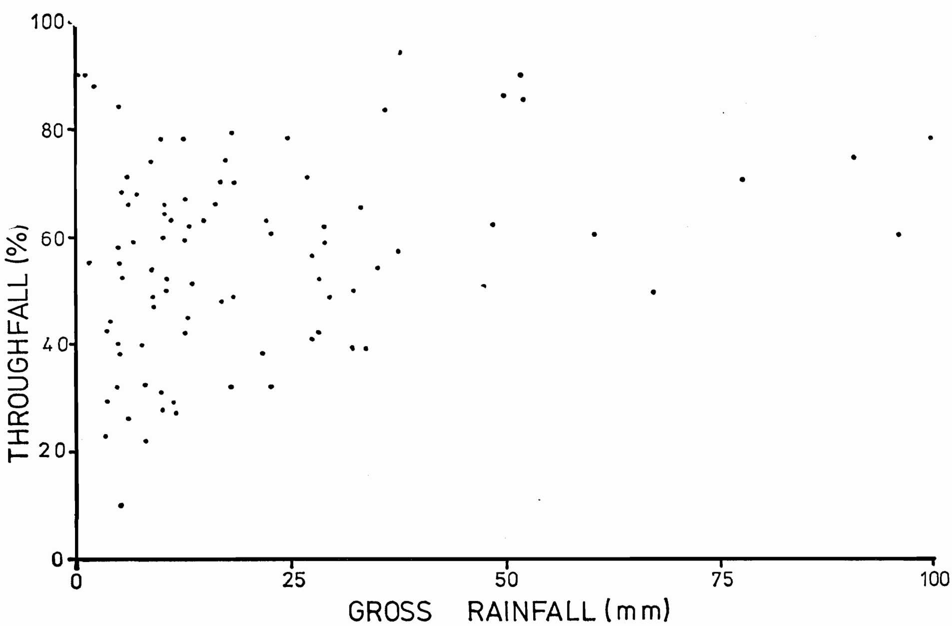

FIG 12—Percentage interception loss-gross rainfall relationship for storm sampling.

TABLE 5 - Interception losses for selected storms

Date measured	Total storm duration hours	Duration of falling rain hours	P mm	IL mm	Estimated evaporation dry periods mm	IL wet periods mm	Evaporation rate wet periods mm/h
5/1/69	10	10	28.7	13.2	2.8	10.4	1.04
18/1/69	14	14	30.0	10.9	2.8	8.1	0.58
28/2/69	36	28	91.9	23.4	5.6	18.3	0.65
13/4/69	15	10	28.5	16.0	4.8	11.2	1.12
23/4/69	-	-	46.7	22.4			
19/12/69	48	46	97.5	36.6	3.6	33.0	0.72
25/12/69	10	10	68.1	33.5	2.8	30.7	3.07
27/12/69	-	-	61.5	23.4			
27/1/70	-	-	101.1	20.8			
9/12/70	51	35	29.2	10.9	8.4	2.5	0.07
28/2/70	16	14	29.2	11.7	3.6	8.1	0.58
8/3/70	12	12	36.3	5.3	2.8	2.5	0.21
2/4/70	-	-	34.0	20.6			
6/4/70	10	10	27.9	11.7	2.8	8.9	0.89
7/12/70	-	-	22.9	3.8			
15/12/70	36	24	37.9	15.7	7.6	7.1	0.30
7/1/71	-	-	52.8	6.9			
2/3/71	98	25	32.5	19.3	9.2	10.1	0.40
18/4/71	88	53	49.3	18.0	14.0	4.0	0.08
10/5/71	37	12	35.7	16.0	10.4	5.6	0.47
15/5/71	-	-	32.5	15.8			
1/6/71	35	35	78.7	22.4	2.8	19.6	0.56
6/6/71	-	-	50.8	6.6			

periods has been calculated at the rate of 0.4 mm/h with a maximum of 2.8 mm for any given period, this being near the estimate for interception storage. No account has been taken of different day and night rates. From the interception loss for wet periods, the rate of evaporation of intercepted water during falling rain was calculated. Only four of the 15 storms had evaporation rates less than the maximum found by Rutter (1967). Many of the rates were in the range 0.40-0.72 mm/h, rates that were higher than those used to make allowance for evaporation in dry periods. Some rates, such as that recorded on 25/12/69, are obviously in error. Errors in gross rainfall measurement, or under sampling of throughfall drip points would probably account for these.

It is possible, however, that the rates of evaporation of intercepted water by mountain beech forests may be higher than those given by Law (1957) and Rutter (1967) for coniferous stands because the data used, although highly variable, appears to be consistent overall. For example, the relationships between gross rainfall and interception loss determined by linear regression analysis were highly significant and did not vary significantly from year to year or site to site. Furthermore, annual interception losses were similar from year to year, and 73% of the evaporation rates calculated exceeded 0.4 mm/h, although the results above 1.0 mm/h probably reflect measurement errors. In addition, Aldridge & Jackson (1973) have measured interception losses of a related species, *N. truncata,* to be the same at 39%.

The lack of relevant instrumentation combined with the extreme site to site variation of micrometeorological elements in the Craigieburn mountain environment precluded verification of these evaporation rates using energy relation methods. If these rates are high, then either stem drip or bark and lichen retention are very significant or gross rainfall has been seriously overestimated. Only a more intensively instrumented and rigorous study taking leaf energy balances and vapour transport into account could verify whether these evaporation rates are real.

ACKNOWLEDGMENTS

I wish to acknowledge the work of Dr H. M. Keller who set up this study, and of Mrs J. Orwin and Dr C. L. O'Loughlin in assisting in the preparation of this paper.

REFERENCES

ALDRIDGE, R. and JACKSON, R. 1973: Interception of rainfall by hard beech (**Nothofagus truncata**) at Taita, New Zealand. **N.Z. J. Sci. 16 (1):** 185-98.

AUSSENAC, G. 1968: Interception des precipitations par le couvert forestier. **Ann. Sci. for. 25 (3):** 135-56.

BELL, F. C. and GATENBY, M. T. 1969: Effects of exotic softwood afforestation on water yield. **Bull. Water Resources Found. Aust. 15:** 93 pp.

DABRAL, B. G. and SUBBA RAO, B. K. 1969: Interception studies in Sal (**Shorea robusta**) and Khair (**Acacia catechu**) plantations—New Forest. **Indian For. 95 (5):** 314-23.

De WALLE, D. R. and PAULSELL, L. K. 1969: Canopy interception, stemflow and streamflow on a small drainage in the Missouri Ozarks. **Res. Bull. Montana Agric. Exp. Sta. 951:** 26pp.

EIDMANN, F. E. 1959: Die interception in Buchen und Fichtenbestanden; Ergebnis mehrjahriger untersuchungen im Rothaargebirge (Sauerland). **Int. Assn. Scientific Hydrology Publ. 48:** 5-25.

FREESE, F. 1967: Elementary statistical methods for foresters. **Agric. Handb. U.S. Dep. Agric. 317:** 87pp.

HAMILTON, E. L. and ROWE, P. B. 1949: Rainfall interception by chaparral in California. **U.S. For. Serv. Calif. For. Range Exp. Sta.:** 43pp.

HELVEY, J. D. and PATRIC, J. H. 1965a: Canopy and litter interception of rainfall by hardwoods of the Eastern United States. **Water Resources Res. 1 (2):** 193-206.

——— 1965b: Design criteria for interception studies. **Int. Assn. Scientific Hydrology Publ. 67:** 131-7.

JACKSON, R. J. and ALDRIDGE, R. 1973: Interception of rainfall by kamahi (**Weinmannia racemosa**) at Taita, New Zealand. **N.Z. J. Sci. 16 (3):** 573-90.

LAW, F. 1957: Measurement of rainfall, interception and evaporation losses in a plantation of sitka spruce trees. **Int. Assn. Scientific Hydrology Publ. 44:** 397-411.

LEONARD, R. E. 1961: Interception of precipitation by northern hardwoods. **U.S. For. Serv. Ntheast For. Exp. Sta. Pap. 159:** 16pp.

MILLER, R. B. 1963: Plant nutrients in hard beech. III. The cycling of nutrients. **N.Z. J. Sci. 6 (3):** 388-413.

MORRIS, J. Y. 1965: Climate observations in the Craigieburn Range, New Zealand. **N.Z. J. Sci. 8 (4):** 556-82.

NIHLGARD, B. 1969: Distribution of rainfall in Beech and Spruce forest, a comparison. **Bot. Notiser 122 (2):** 308-9.

NOIRFALISE, A. 1959: Sur l'interception de la pluie par le couvert dans quelques forets belges. **Bull. Soc. For. Belg. 66 (10):** 433-9.

OVINGTON, J. D. 1954: A comparison of rainfall in different woodlands. **Forestry 27 (1):** 41-53.

REYNOLDS, E. R. C. and LEYTON, L. 1963: Measurement and significance of throughfall in forest stands. **In** Rutter, A. J., Whitehead, F. H. (Editors). "The Water Relations of Plants." Pp. 127-41. Blackwell Scientific Publications, London.

RUTTER, A. J. 1963: Studies in the water relations of **Pinus sylvestris** in plantation conditions. I. Measurements of rainfall and interception. **J. Ecology 51 (1):** 191-203.

——— 1967: An analysis of evaporation from a stand of Scot's pine. **In** Sopper, W. E., Lull, H. W. (Editors). "International Symposium on Forest Hydrology". Pp. 403-17. Pergamon Press, Oxford.

SHENG, T-C. and KOH, C-C. 1967: Forest hydrology research in Taiwan, Republic of China. **In** Sopper, W. E., Lull, H. W. (Editors). "International Symposium on Forest Hydrology." Pp. 89-94. Pergamon Press, Oxford.

SOKAL, R. R. and ROHLF, F. J. 1969: "Biometry". P. 538. W. F. Freeman and Co., San Francisco.

VOIGHT, G. K. 1960: Distribution of rainfall under forest stands. **For. Sci. 6 (1):** 2-10.

VOIGHT, G. K. and ZWOLINSKI, M. J. 1964: Absorption of stemflow by bark of young red and white pine. **For. Sci. 10 (3):** 277-82.

ZINKE, P. J. 1967: Forest interception studies in the United States. **In** Sopper, W. E., Lull, H. W. (Editors). "International Symposium on Forest Hydrology." Pp. 137-61. Pergamon Press, Oxford.