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Interception per Canopy in a Multi-Storied Largetooth Aspem Community

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ABSTRACT

This paper presents matematical equations describing the relationships between the amount of interception per canopy per storm and the amount of gross rain per storm for four different canopies in a 55-year-old, multi-storied forest community. The curves representing the relationships were curvilinear. As gross rain per storm increased, the amount of interception per storm increased but at a decreasing rate. Variations in vegetal structure on different sample plots had a marked effect on interception curves of two of the four canopies: an understorey canopy comprising tree species and an understorey canopy comprising fern species.

INTERCEPTION PER CANOPY IN A MULTI-STORIED LARGETOOTH ASPEN COMMUNITY

by

John R. Clements[1]

INTRODUCTION

The purpose of this paper is to present matematical relationships between the amount of interception per storm and the amount of gross rain per storm for each of four different canopies in a multi-storied largetooth aspen (*Populus grandidentata* Michx.) forest community. The influence of variations in structure within the stand are reported also.

The aim of the analysis in this paper was to find out what the mathematical relationship might be so that interception per storm might be easily computed for other aspen communities similar in age, structure and climate.

Expressing interceptions per canopy per storm directly as a function of gross rain per storm eliminates the need for many other mathematical calculations, particularly as interception is normally computed as the difference between net rain and gross rain, and net rain is the sum of throughfall and stemflow. The many computations of throughfall and stemflow were made for each storm in summer 1969 for each canopy in turn in the multi-storied aspen community, starting with the uppermost canopy (Clements, 1971). The computed values of interception per canopy per storm and the amounts of gross rain per storm for summer 1969 are the basic data for the analysis in this paper.

Interception is defined in this paper as the amount of rain water prevented by the vegetation from reaching the ground. Therefore interception includes rain water withheld by the vegetation (i.e. leaves and bark of branches and stems) and evaporated after the storm, rain water evaporated from the vegetation surfaces during the storm, and rain water absorbed by the plants into their transpirational streams and later transpired.

Gross rain is defined as the rain measured about 0.76 m above the ground in a clearing near the forest stand and presumed to fall on the forest community. A storm is defined as any rainy period separated from any other rainy period by at least six hours, and storm size is the amount of rain that falls during a storm.

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The equations presented in this paper can be used to evaluate interception per storm by all the vegetation together, or by each canopy separately for storm size-distributions different from that of summer 1969. The evaluations can be made in the community in this study or in other aspen communities of similar age, composition, structure and climate. The evaluations will be valid in the range of storm sizes from 4 to 26 mm for the aspen canopy and for 2 mm to about 50 mm for the other canopies.

THE SITE

The field work, upon which this analysis was based, was done near Petawawa Forest Experiment Station, Chalk River, Ontario, Canada (46°N lat., 77.5°W long.).

The physiography, soils and climate were described in detail by Clements (1971). In brief, the site is on the Precambrian Shield and was glaciated last by Pleistocene ice. The underlying bedrock is Precambrian granitic gneisses and granite, and the soils, shallow in many places, are of glacial origin. The soils are mainly fine to medium wind-blown sands re-worked from deltas in ancient glacial lakes.

The regional climate is continental with local mean annual precipitation of 78.84 cm. Rainfall per day exceeds 2.54 cm (1.0 in.) an average of two days per year, and the mean number of raindays per year is 100 including days when only a trace is recorded (Canadian Forestry Service, 1969). Mean annual potential evapotranspiration by Thornthwaite's formula is 55.9 cm (Fraser, 1967).

THE COMMUNITY

The aspen stand was about 55 years old and the aspen trees were about 10 to 30 m tall.

Beneath the crown canopy layer of the largetooth aspen trees, there were three other crown canopy layers. They were red maple (*Acer rubrum* L.), hazel (*Corylus cornuta* Marsh.) and bracken fern (*Pteridium aquilinum* (L.) Kuhn), in decreasing order of height of the canopy above the ground surface. The community composition and structure were described in detail by Clements (1971).

The crown canopy of only the largetooth aspen trees was continuous. The crown canopies of the other species were discontinuous, and the proportion of the ground area covered by these canopies is defined as crown coverage. Variations in crown coverage and vegetal structure on four sample plots within the stand are described in Table 1. These are the same four plots for which the monthly budgets of interception were made based on 1969 storm-size frequency distribution (Clements, 1971).

TABLE 1

Description of four typical plots in the mature largetooth aspen stand. (From Clements, 1971).

Plot and item	Canopy			
	Largetooth Aspen	Red Maple	Hazel 1/	Bracken Fern 1/
9D8				
No. stems/ha	543.4	494.0	18,300	57,300
Basal area/ha - m^2/ha	15.3	0.9	-	-
Diameter range - cm	10.2-27.9	1.3-15.9	0.9-2.7	0.8-1.2
Crown coverage - % 2/	100	30	70	90
9E7				
No. stems/ha	741.0	666.9	13,300	63,700
Basal area/ha - m^2/ha	20.7	3.6	-	-
Diameter range - cm	10.2-27.9	1.3-20.3	0.9-1.8	0.6-1.1
Crown coverage - % 2/	100	30	30	100
9E8				
No. stems/ha	741.0	1457.3	29,100	31,900
Basal area/ha - m^2/ha	18.4	4.1	-	-
Diameter range - cm	12.7-27.9	0.6-15.2	0.9-2.4	0.4-0.9
Crown coverage - % 2/	100	80	60	50
9E11				
No. stems/ha	839.8	2568.8	21,700	25,500
Basal area/ha - m^2/ha	35.9	4.3	-	-
Diameter range - cm	15.2-30.5	1.3-12.7	0.9-3.7	0.6-1.0
Crown coverage - % 2/	100	90	80	40

1/ For "diameter range" read "height range" in meters.

2/ Crown coverage is the proportion of the plot covered by the canopy. It does not refer to canopy density or leaf area index.

METHODS

The interception data computed by Clements (1971) on a per storm basis were used as the data for this paper. Interception per storm had been computed from the formula

$$I_c = P_a - (S_a + T_a) \qquad \text{mm per storm} \qquad (1)$$

where $\underline{I_c}$ = interception per canopy per storm in mm

$\underline{P_a}$ = adjusted gross rain per storm in mm

$\underline{T_a}$ = adjusted throughfall per storm in mm

$\underline{S_a}$ = adjusted stemflow per canopy per storm in mm.

The adjustments made to gross rain, throughfall and stemflow are described in detail by Clements (1971). They were applied to account for the discontinuities of the different crown canopies. Values of stemflow and throughfall were computed from smoothed curves so that the natural variation inherent in the original field data are not apparent in these computed interception values. The number of interception values for each canopy ranges from 25 to 29, based on the summer 1969 storm-size distribution ranging from about 1 to 48 mm.

The values of interception per storm were plotted over the amounts of gross rain per storm. The plotting resulted in points for smooth curves, a separate curve for each canopy on each forest sample plot. Also, values of total interception per storm by all canopies together were plotted over the amount of gross rain per storm. This plotting also yielded points for smooth curves, one for each forest sample plot.

The equation

$$I_c = \frac{a(P - c)}{b + P - c} \qquad \text{mm per storm} \qquad (2)$$

where $\underline{I_c}$ = interception per storm in mm

$\underline{P}$ = gross rain per storm in mm

$\underline{a}$, $\underline{b}$, $\underline{c}$ are equation coefficients,

was fitted to the points for the largetooth aspen, red maple, hazel canopies and to the points for total interception per plot.

The equation

$$I_c = \frac{a\ (P - c)^2}{b + P - c} \qquad \text{mm per storm} \qquad (3)$$

where the symbols are the same as those in equation (2), was fitted to the bracken fern data.

Equation (2) is a possible functional representation of the theoretical graph constructed by Leonard (1967, p. 134) to show the theoretical relationship between interception and rainfall. This equation did not fit the bracken fern data and equation (3) was used instead.

The coefficients of the regression equations were computed by least squares analysis. The values of R^2 ranged between 0.998 and 0.999998. The original field data included storm sizes to about 50 mm in respect of the red maple, hazel and bracken fern canopies, and about 26 mm in respect of the aspen canopy. In this paper, the interception curves for aspen were extrapolated to 50 mm. Admittedly, this degree of extrapolation may not be justified, but it permitted a comparison among forest sample plots of total interception by all standing vegetation. The amount of uncertainty associated with extrapolated interception for these large storms is now known, but storms larger than about 25 mm are uncommon at Chalk River.

RESULTS

The curves showing for the various canopies the relationship between the amount of interception per storm and the amount of gross rain per storm are in Fig. 1. The coefficients of the equations are in Table 2.

Total interception per plot per storm in relation to the amount of gross rain per storm is shown in Fig. 2. The coefficients for the equations in this figure are in Table 2.

DISCUSSION

The graphs in Fig. 1 show the curvilinear relationship between interception per canopy per storm and gross rain per storm. The amount of interception per storm increased as storm size increased and the rate of increase was different for the various canopies. For most of the observed range in storm size the differences in interception per storm between the canopies were marked and the amounts of interception per canopy per storm were not in the same order as that of the crown positions in the forest stand profile.

The aspen and hazel canopies intercepted small quantities of rain throughout the entire range of observed storms, as indicated by the shallow rise in the curves for these canopies. Aspen is known to be thin-crowned and the leaves and the bark of the branches and upper part of the main stem are waxy and smooth. Hazel leaves are rough but the crown layer is shallow.

TABLE 2

Coefficients of the equations that describe the relationship between the amount of interception per canopy per storm and the amount of gross rain per storm. The coefficients for the largetooth aspen, red maple and hazel canopies and for all canopies together are for equation (2) referred to in the text; for bracken fern the coefficients are for equation (3).

Plot and canopy	Equation coefficients		
	a	b	c
9D8			
Largetooth aspen	1.90	20.09	-8.94
Red maple	105.22	1155.36	0.28
Hazel	3.21	99.47	-5.70
Bracken fern	0.10	19.85	-6.27
All canopies	122.45	567.05	-4.01
9E7			
Largetooth aspen	1.71	17.73	-9.38
Red maple	18.69	212.32	0.26
Hazel	0.77	47.44	-4.98
Bracken fern	0.11	19.04	-6.16
All canopies	84.88	424.20	-4.00
9E8			
Largetooth aspen	1.46	11.89	-8.05
Red maple	153.53	640.75	0.27
Hazel	1.12	38.90	-5.91
Bracken fern	0.04	24.89	-7.80
All canopies	111.28	351.21	-2.48
9E11			
Largetooth aspen	1.22	7.35	-6.84
Red maple	192.30	717.44	0.26
Hazel	2.17	75.99	-7.78
Bracken fern	0.03	26.27	-8.17
All canopies	139.18	415.10	-2.49

The red maple and the bracken fern canopies had large capacities to intercept rain, as indicated by the steeply rising curves. The high capacity of red maple to intercept rain is likely due to the moderately rough leaves and thick crowns. The bark of the branches and stem is smooth, although unlike smooth aspen bark, is not waxy. The high capacity of the bracken fern canopy to intercept rain is likely due to the large number of plants per hectare which, taken together, provided a large plant surface area for retaining rain water.

The variations in vegetal structure had a marked effect on the interception curves of some canopies but not others. The curves for red maple were steep for the forest sample plots where red maple crown coverage was high (80% on plot 9E8 and 90% on plot 9E11) and were shallower for the plots where red maple crown coverage was lower (30% on plots 9D8 and 9E7). Similarly for the curves for bracken fern; the curves were steeper where bracken fern crown coverage was high (90% on plot 9D8 and 100% on plot 9E7) than where bracken fern crown coverage was lower (50% on plot 9E8 and 40% on plot 9E11). For other canopies there was little change in the slope of the interception curves from sample plot to sample plot.

The effects of the variations in vegetal structure on the interception curves for the separate crown canopies are reflected in the curves for total interception in Fig. 2. For small storms there were small differences among the forest sample plots in the total amounts of interception per storm. Differences among the plots got increasingly large as storm size increased.

In general, equation (2) states that the amount of interception per storm increases as the amount of gross rain per storm increases, but that the rate of change in the amount of interception per storm eventually decreases to zero as gross rain per storm becomes large.

Equation (3) in general, states that the amount of interception per storm increases as the amount of gross rain per storm increases, but that the rate of change of the amount of interception per storm eventually increases to a constant value (numerically equal to the a coefficient) as gross rain per storm becomes large.

In the range of the largest values of gross rain measured in the field, all interception curves (for individual canopies and for all canopies together) were rising and at nearly constant rates. This could mean, in terms of the interception curve in Fig. 1 of Leonard (1967), that for the largest measured storms in this study maximum storage by the vegetation had not been reached, although the maximum amount of evaporation (as opposed to storage) from the vegetation surfaces per storm may have been reached.

Alternatively, these interception curves could mean that the maximum storage by vegetation was filled (or nearly filled) and evaporation per storm was increasing at a constant rate (or nearly constant rate).

Figure 1. The relationship between the amount of gross rain per storm and interception per storm for various canopies on four different sample plots in a multi-storied largetooth aspen stand. The equation coefficients for these curves are in Table 2. The dashed part of the curve for the aspen canopy is based on extrapolated data.

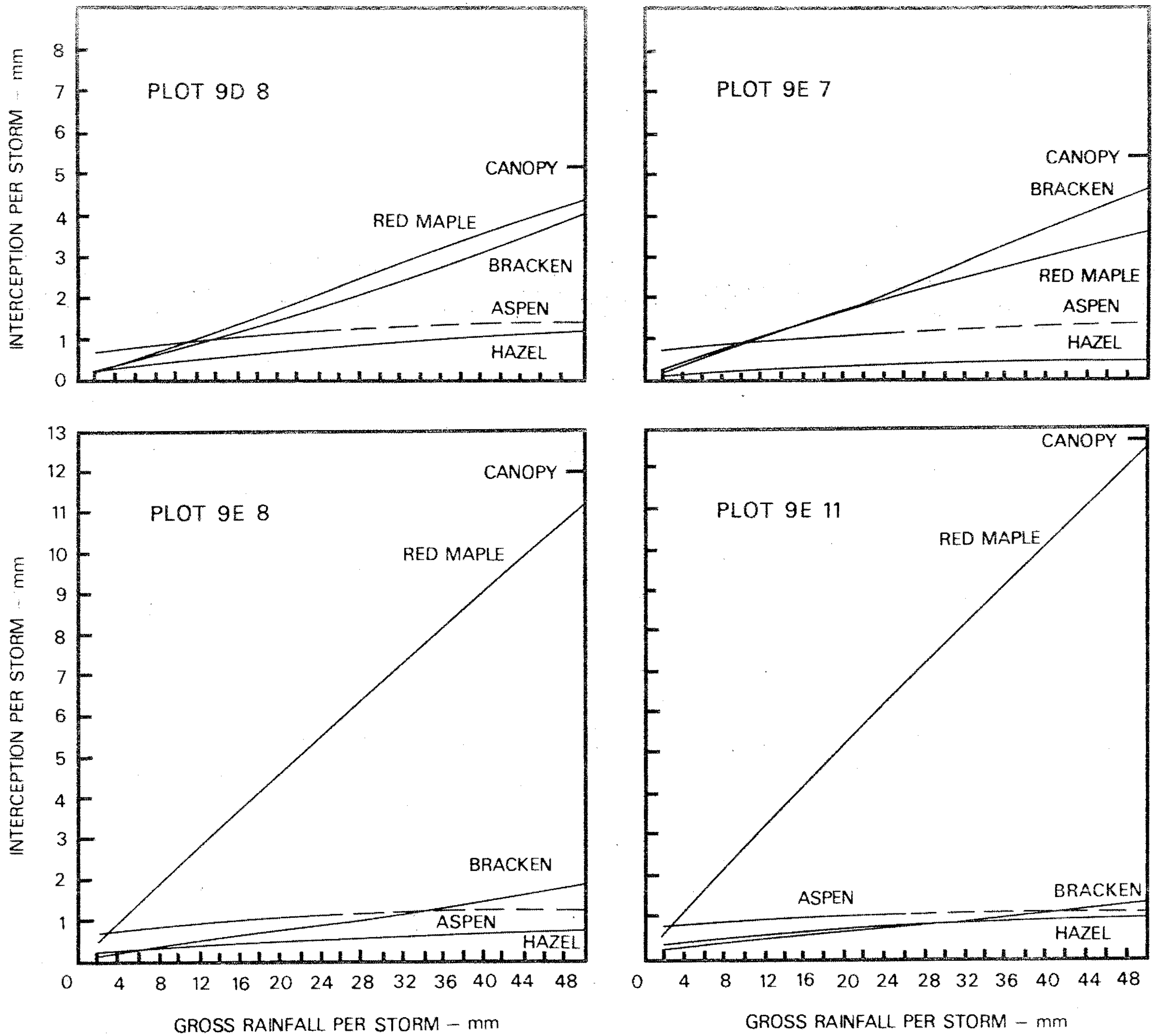
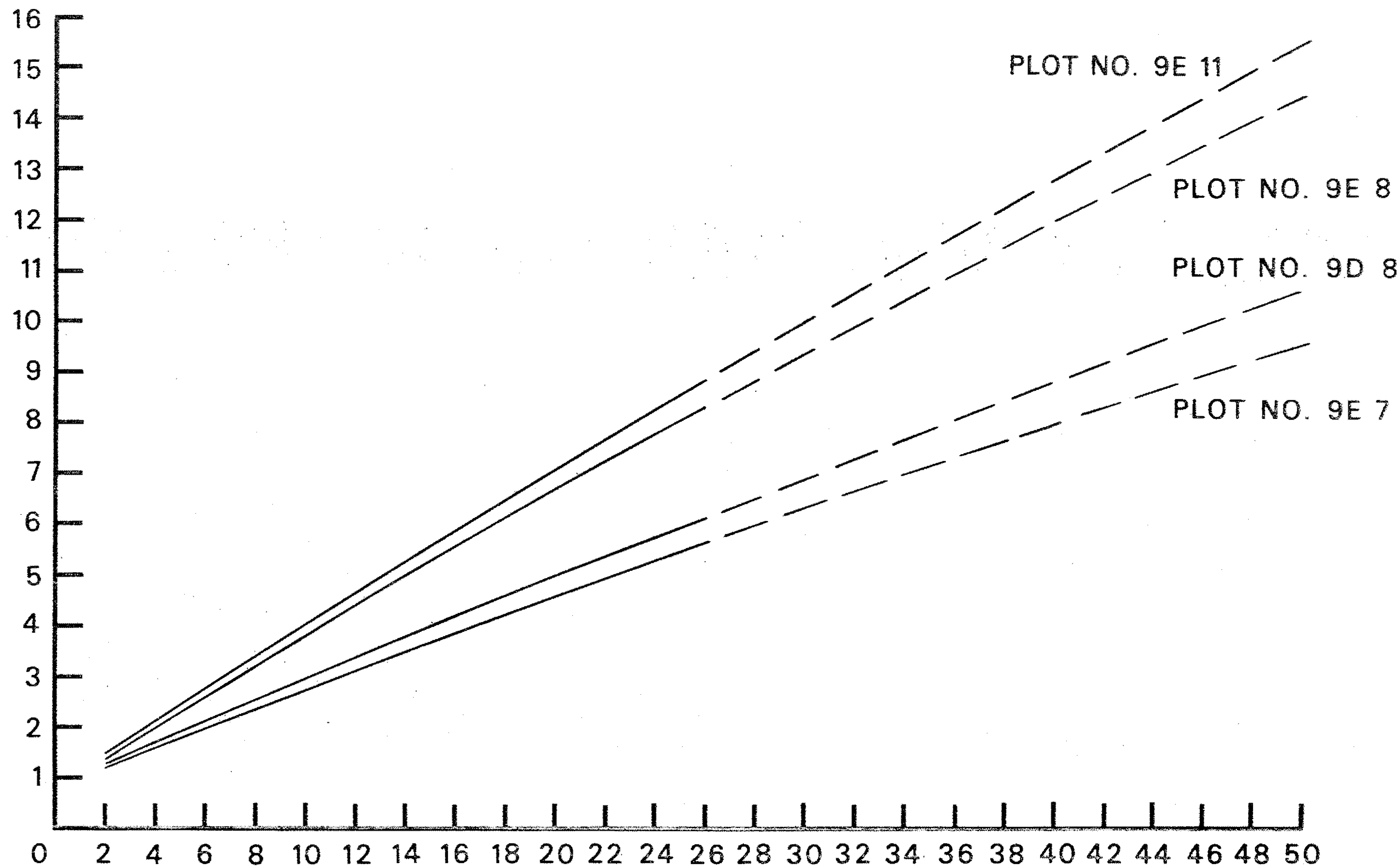

PLOT 9D 8
PLOT 9E 7
PLOT 9E 8
PLOT 9E 11
CANOPY
RED MAPLE
BRACKEN
ASPEN
HAZEL
INTERCEPTION PER STORM – mm
GROSS RAINFALL PER STORM – mm

Figure 2. The relationship between the amount of gross rain per storm and interception by all the vegetation on four different sample plots in a multi-storied largetooth aspen stand. The coefficients are in Table 2. The dashed part of the curves are based in part on extrapolated data for the largetooth aspen canopy.



PLOT NO. 9E 11
PLOT NO. 9E 8
PLOT NO. 9D 8
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The latter interpretation is in part consistent with the views of Horton (1919) and Kittredge (1948). According to these authors the relationship between the amount of interception per storm and the amount of gross rain per storm is linear, i.e. the interception per storm increases at a constant rate as gross rain per storm increases. Furthermore, the curves in Fig. 1 based on equation (2), if extrapolated to the origin, are similar in form to the curve in the scatter diagram of Rutter (1963, p. 197) for Scots pine (*Pinus sylvestris* L.), and to interception-precipitation curves of Hamilton and Rowe (1949) for shrubby vegetation in California.

In any case, the use of equations (2) and (3) should be considered tentative and predictive in the range of measured storms.

The *c* coefficients in Table 2 for equations (2) and (3) should provide an estimate of the size of the storm at which interception begins; for the aspen canopy interception starts with the smallest rainfall, but for the red maple canopy interception starts when throughfall under the aspen canopy starts. Similarly for the hazel and bracken fern canopies interception starts when throughfall under the upper canopy starts. In the case of the aspen canopy, no attempt was made to force the curve through the origin, that is, by omitting the *c* coefficient.

Theoretically, at least, the value of *c* should be zero for the aspen canopy, and successively larger for each lesser canopy in turn starting with the red maple canopy. Hence all values of *c* should be positive. In these results, however, many computed values of *c* were negative, due to a combination of sampling errors in the field measurements, and the omission in the stemflow analyses (Clements, 1971) of stemflow data for storm sizes less than about 2 to 4 mm.

The curves presented in this paper are useful for evaluating variations in total monthly or total summer interception by the various canopies and by all standing vegetation in relation to storm-size distributions different from the one in summer 1969. However, as they are valid only for the period when trees and shrubs are in leaf and bracken fern fronds are alive, the curves should be used with caution especially for June and September. Further, the curves can only be used where climate is similar to that in the general area of the study site.

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