Differences in Rainfall and Soil Moisture Distribution in a Northern Boreal Forest Stand*

By Don Gill **

Summary: Rainfall interception by tree crowns in a mature coniferous forest in the Mackenzie River Delta, Northwest Territories, Canada, causes a loss of approximately 25 percent of the annual rainfall. Such reduction in the amount of water reaching the ground causes a corresponding decrease of approximately 25 percent in the soil moisture budget.

Zusammenfassung: Die Interzeption durch die Baumkronen eines ausgewachsenen Koniferenbestandes im Mackenzie Delta (Northwest Territories, Kanada) bewirkt einen Verlust von rd. 25 % des Jahresniederschlages. Eine derartige Reduktion der den Waldboden erreichenden Wasserspende führt zu einer Verringerung des Bodenfeuchtehaushalts um ebenfalls ca. 25 %.

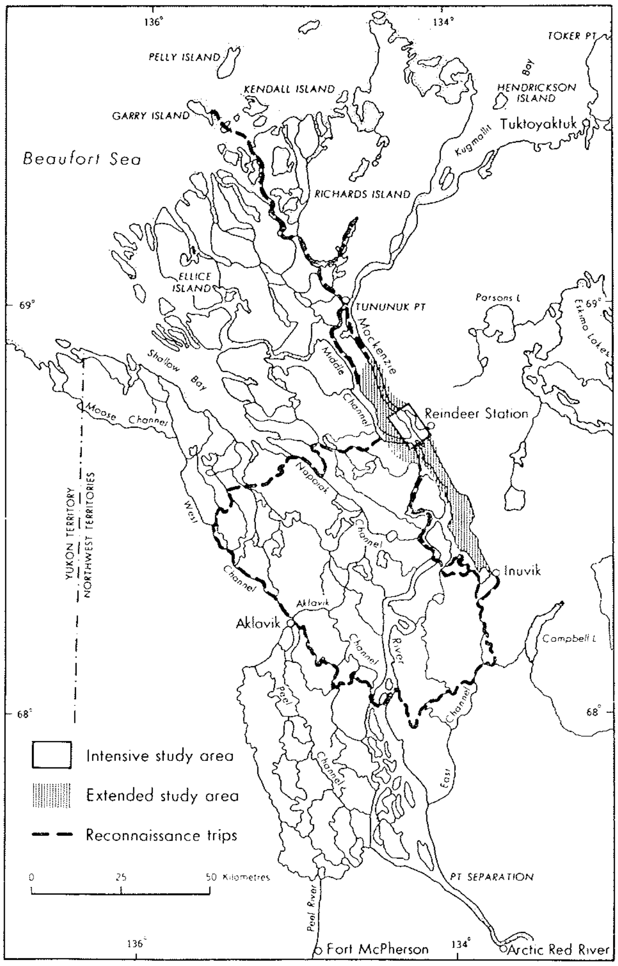

Fig. 1: Study area within the Mackenzie Delta.
Abb. 1: Untersuchungsgebiet innerhalb des Mackenzie Deltas.

* Contribution No. 21, Boreal Institute for Northern Studies, The University of Alberta, Edmonton, Canada.

** Dr. Don Gill, Director, Boreal Institute for Northern Studies, The University of Alberta, Edmonton, Alberta, Canada.

Introduction and Purpose

In 1966, the Journal of Soil and Water Conservation published an article on rainfall interception in coniferous forests of southeast Alaska (Patric, 1966). The purpose of the present paper is to report on a similar study in the Mackenzie River Delta, Northwest Territories, Canada, and to draw some comparisons with Patric's study. Although studies of rainfall interception by trees outnumber most other aspects of forest hydrology, this is the first attempt to measure under-canopy rainfall distribution in the boreal forest of the Canadian Northwest. In addition, data are presented to show a correlation between rainfall interception and the distribution and reduction of soil moisture in a northern coniferous stand.

Study Location

Rainfall interception loss was measured in a mature stand of alluvial white spruce *(Picea glauca)* 6 miles (9.5 km) northwest of Reindeer Station, Northwest Territories (Fig. 1). The vegetation of this area has been analyzed by Gill (1971; 1972; 1972a-d). The stand is typical of the Mackenzie Delta's extensive old-growth forests that occupy the higher levees. Average tree height is 40 feet (12 m); diameter at breast height (dbh) ranges from 7 to 12 inches (18-30.5 cm); canopy density is 60 to 70 percent; tree ages range from 170 to 290 years. The stand has a relatively sparse, 6 to 8 foot (2-2.5 m) tall willow (*Salix* spp.) and alder *(Alnus crispa)* understory. Ground cover consists of a thin layer of the mosses *Hylocomium splendens* and *Aulacomnium palustre*, covering 80 percent of the surface. The remainder of the ground is composed of exposed sediment. The climate of the Mackenzie Delta area is described by Mackay (1963), Abrahamsson (1966) and Gill (1971). The coastal portion of the Mackenzie Delta lies within the Arctic climatic zone and its southern portion is in the Subarctic; the study site is transitional between the two. Mean daily temperatures at Inuvik, 30 miles (48 km) southeast of the study site, range from —22°F (—30°C) in January to 56°F (13.5°C) in July. Precipitation is low; rainfall averages 4.3 inches (11 cm) each summer, and snowfall averages 68 inches (173 cm), for a total annual precipitation of about 10 inches (25 cm). Most of the precipitation in the summer months comes in the form of rain, the maximum usually occurring in July or August. Although the rainfall is light, thunderstorms do infrequently occur, and stations during such storms may record rainfalls of .5 inch (1.3 cm) or more in 24 hours.

Fig. 2: White spruce *(Picea glauca)* in the study area of the Mackenzie Delta with a canopy density of 60 to 70 %.

Abb. 2: Weißfichte *(Picea glauca)* im Untersuchungsgebiet mit einer Kronenschlußdichte (Bedeckungsgrad) von 60 bis 70 %.

Field Work

Summer field work was carried out during the 1966 field season; supplemental observations were made during the summer of 1971. Winter measurements were taken in February 1967 and March 1972.

Methods

From June 30 to September 4, 1966, gross rainfall, throughfall, and stemflow were sampled in a radiating grid beneath one randomly chosen spruce tree within a stand with a spatial distribution as illustrated in Fig. 2. Gross rainfall was sampled with two standard U. S. Weather Bureau 8-inch (20.4 cm) rain gauges placed in an open area within 400 yards (365 m) of the study site. Throughfall was measured at ground level with 20 no. 10 cans; stemflow was sampled with four no. 10 cans flattened against the

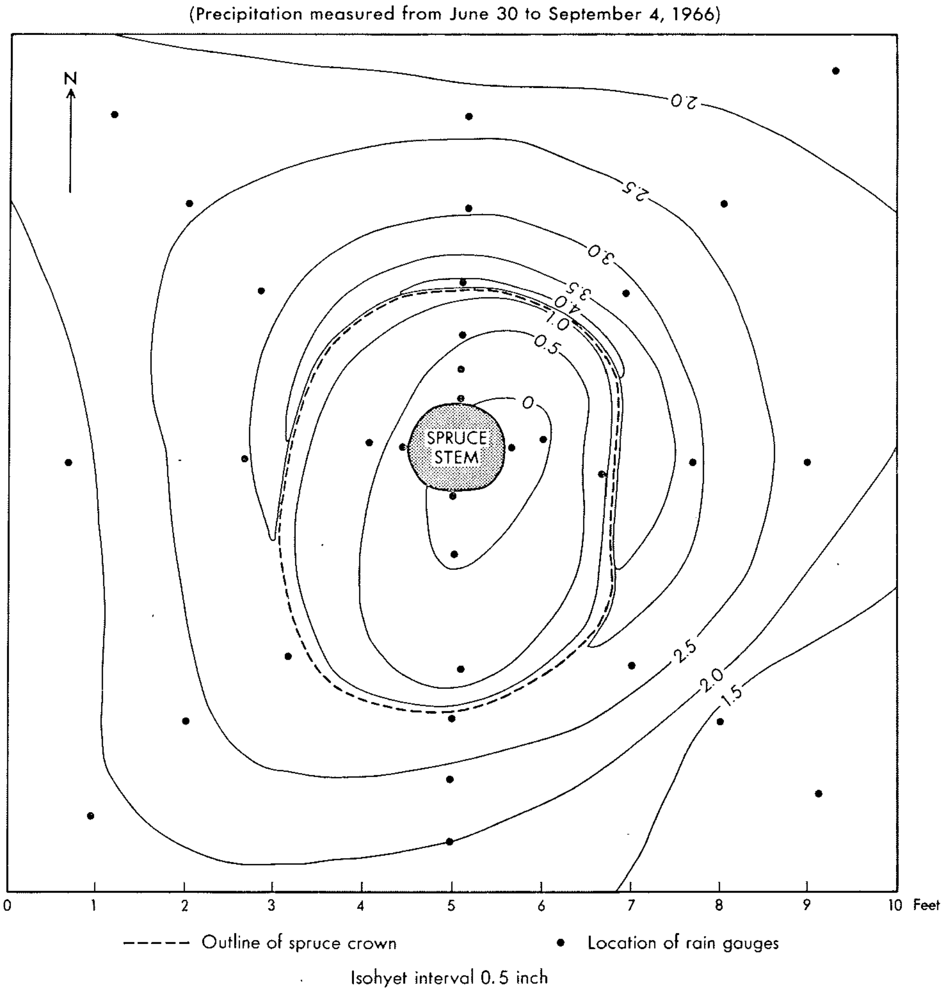

Fig. 3: Isohyet map showing the influence of a spurce crown on the distribution of rainfall in a *Picea* community.

Abb. 3: Isohyetenkarte, die den Einfluß einer Baumkrone auf die Niederschlagsverteilung in einem *Picea*-Bestand zeigt.

spruce stem at a height of four feet (1.2 m). Fig. 3 shows rain gauge locations. To test the representativeness of data gathered in the intensive study plot, samples were taken in a similar fashion from a second (paired) randomly-selected plot. A different sample location was selected after each rainfall.

One set of snow-depth measurements was made at the study site in February 1967. These observations were augmented by other snow measurements taken in March 1972. In conjunction with the precipitation measurements, soil moisture values were measured 24 hours after a rainfall in late summer to sample the influence of rainfall interception on soil moisture beneath spruce trees. In early September 1966, 20 soil samples were taken from beneath the tree shown in Fig. 4. Soil within the mineral horizon (beneath the mor layer) was sampled at a depth of two inches (2.5 cm) and at a six-inch (15 cm) interval. Similar measurements were taken in another sample plot for comparison. Moisture percentages were later determined at the Inuvik Research Laboratory through the standard method of weighing, drying, and re-weighing.

Results

Rainfall occurred on 20 separate days during the sample period, producing a total of 2.5 inches (6.5 cm) in the open location, and 2 to 2.5 inches (5-6.5 cm) of rainfall in the

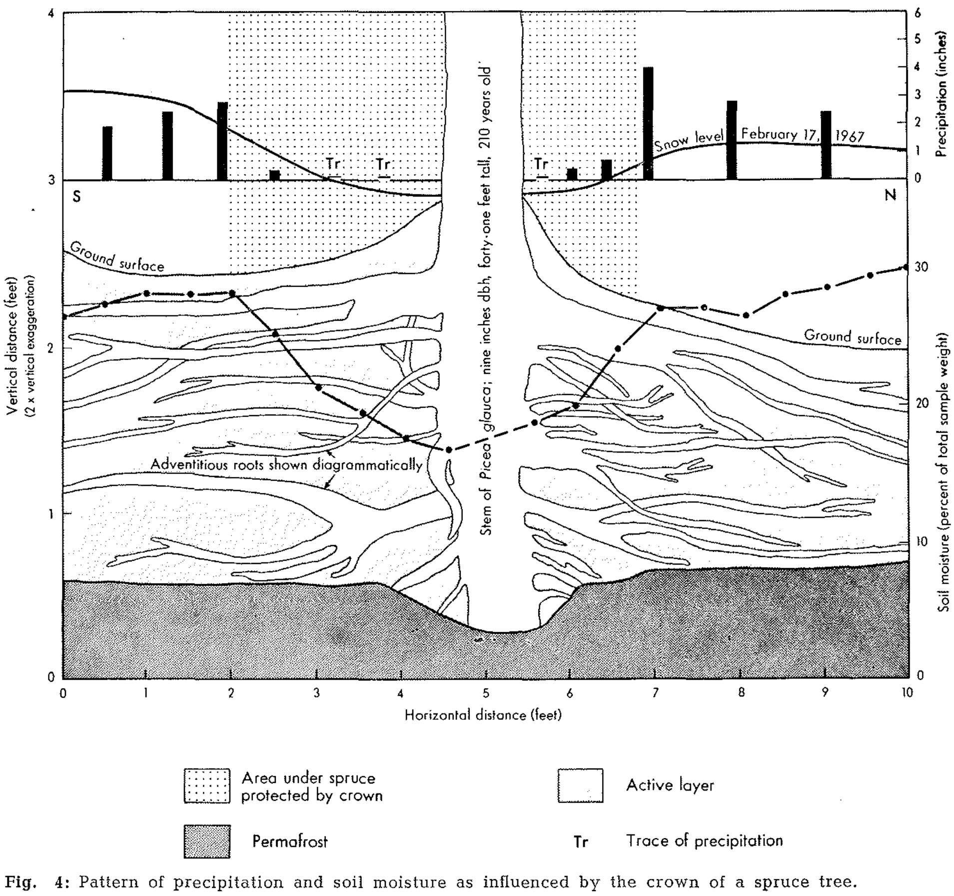

Fig. 4: Pattern of precipitation and soil moisture as influenced by the crown of a spruce tree.
Abb. 4: Der Einfluß einer Fichtenkrone auf Niederschlagsverteilung und Bodenfeuchte (im Aufriß).

general vicinity of the study plot (Fig. 3) and the paired sample plots. Gross rainfall during individual storms varied from .005 to .81 inch (.015-2.05 cm). Total throughfall varied from a trace to .70 inch (1.75 cm), depending on the location beneath tree crowns. The ground area directly below the trees received approximately 15 percent of the gross rainfall. This loss was partially compensated by the greater amount which fell around the periphery of crowns due to shedding and leaf-drip (Figs. 3, 4), so that the total amount of rain intercepted by trees was in the order of 25 percent. Data gathered from the moving sample plot compared favorably with data gained in the stationary plot: throughfall and stemflow measurements from each plot were always within ± 6 percent of each other. This figure, however, should be accepted only with caution, as it is well known that there is an inherent error in all rainfall sampling.

Limited information on the amount of snow interception by spruce trees indicates that about 40 percent of the snowfall on this stand is intercepted by spruce crowns. The February 1967 measurements, which are similar to measurements taken in March 1972, are shown in Fig. 4.

Results of the soil moisture measurements are summarized in Fig. 4; soil moisture ranged from 30 percent at a distance of 3.2 feet (1 m) from the crown-protected area to 16.5 percent within the most protected location adjacent to the stem. The graphed values shown in Fig. 3 compared favorably with measurements taken in a second plot on the same date; the spatial variation in soil moisture was similar (depressed toward the tree stem) and moisture values were of the same order (generally within ± 4 percentage points of each other).

Discussion

Stemflow during the period of measurement was negligible, a common condition in northern conifer stands. Trace amounts of stemflow occurred during three storms, but only along the north and west sides of the tree trunks; rain gauges mounted against the south and east sides received no water during the sample period. Additional observations made during storms of varying intensities in 1966 and 1971 suggest that very little stemflow if any reaches the forest floor of spruce stands in the study area; trunks remain dry even during prolonged rainfalls.

Spruce crowns in the Mackenzie Delta thus exhibit a high degree of waterproofness; perhaps the most convincing evidence of non-permeability is the amount of rainfall that concentrates below the outer edge of tree crowns as exhibited in Figs. 3 and 4. Immediately adjacent to the north and northeast edge of this tree, the amount of rain striking the ground rises abruptly from approximately 1 inch (2.5 cm) beneath the crown to 4 inches (10 cm) in the area of drip concentration, then declines to the 2-2.5 inch (5-6.5 cm) figure (gross rainfall) as distance from the tree increases. A ring of greatly concentrated runoff is thus evident around the outside perimeter of the crown. In the Canadian Northwest, white spruce crowns are narrowly columnar in shape, and their branches, particularly along the lower section of the trunk, bend downward (Fig. 2). The consequent overlapping of limbs creates a "shingle" effect thus water runs off rather than penetrates and a circular concentration results.

In all, the amount of rainfall intercepted by the spruce canopy in the study area accounted for an approximate loss of .63 inch (1.6 cm) of water, or 25 percent of the gross rainfall of 2.5 inches (6.5 cm). This is the same figure given by Patric (1966) who reports an interception loss of about 25 percent of the annual rainfall in a mature stand of western hemlock *(Tsuga heterophyla)* and sitka spruce *(Picea sitchensis)* in southeast Alaska. Furthermore, Patric found that his throughfall measurements differed little from those reported for other mature rain forests of western North America. The present study thus suggests that rainfall intercepted by mature coniferous stands may be relatively uniform in contributing to water loss, regardless of location. It certainly helps to extend Patric's findings from the rain forests of western North America to the dry interior boreal forest of the Canadian Northwest.

The graphed values in Fig. 4 illustrate that rainfall interception by the forest canopy may also cause considerable variation in soil moisture. As expected, 24 hours after a rainfall of .045 inch, the soil was drier beneath a tree than away from it. However, the fact that after a very light rainfall the soil was nearly twice as moist away from the crown-protected area as it was directly below the crown suggests a seasonal rather than a temporary condition. Furthermore, samples were taken from near the soil surface, thus differences in soil moisture due to transpiration loss should have been negligible. It thus appears that in addition to normal evaporation and transpiration losses, an approximate reduction of 25 percent of the annual precipitation through interception by tree crowns will cause a corresponding lowering of soil moisture by approximately 25 percent.

In conclusion, an interception loss of some 25 percent of the annual rainfall can be expected in the water budget of similarly dense boreal forest stands in the Canadian Northwest. In addition, all other conditions being equal, a corresponding decrease of 25 percent in the moisture balance near the soil surface, due to rainfall interception, can be expected as well.

Acknowledgements

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