THE INTERCEPTION OF RAIN AND SNOW BY A FOREST OF YOUNG PONDEROSA-PINE

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Introduction

The interception of rain and snow by the forest-canopy is a factor of sufficient magnitude to require its measurement in any complete study of the hydrology of forested watersheds. In experiments set up to measure the relations of watershed-runoff and infiltration to precipitation it is particularly essential to measure net rainfall reaching the soil under the forest-canopy, rather than total precipitation, in order to estimate adequately the amounts of water available for runoff.

The study described in this paper is one phase of watershed-management studies conducted by the Rocky Mountain Forest and Range Experiment Station, in cooperation with the Colorado State College of Agriculture and Mechanic Arts, in the ponderosa-pine type of Colorado. It was designed to determine the amount of precipitation actually reaching the forest-floor under stands of immature ponderosa-pine on small watershed-areas, in order that the amount of water lost by interception might be evaluated and that watershed infiltration-capacities under natural conditions of rainfall might be accurately determined. The study deals with amounts of net precipitation derived from both summer rainfall and winter snowfall but ignores the amount of water reaching the ground as stemflow. Present incomplete studies indicate that stemflow is of minor importance in a stand of immature ponderosa-pine.

Rainfall-interception has been studied by many investigators but no work has been done in the ponderosa-pine type characteristic of the Front Range of the Colorado Rockies. WILM and NIEDERHOF [see 7 of "References" at end of paper] have studied the problem in the lodgepole-pine type in Colorado, finding that under virgin stands approximately 30 per cent of the summer rainfall was intercepted and that by timber-cutting this amount was decreased to as little as eight to ten per cent. DE FOREST [1] found that both herbaceous and tree cover intercept large quantities of rainfall and that the amount depends upon the amount and intensity of the rainfall. ZON [9], HORTON [2], KITTREDGE [4], WICHT [6], and others have also contributed to the general knowledge of rainfall-interception.

Experimental procedure

This experiment was conducted on the upper South Platte River Watershed, in an area typical of the ponderosa-pine type of the Colorado Front Range. Here 70 to 80 per cent of the annual precipitation falls in the form of rain, largely in small showers interspersed with occasional storms of high intensity. In this area six watersheds, supporting stands of immature ponderosa-pine, are being studied to learn the influence of forest-management on surface-runoff, infiltration, and erosion.

Three of the watersheds were used for this study of interception. In each watershed six standard rain-gages were located under tree-crowns and six in large openings near each of the interception-gages. The location of each gage was determined by random selection from all available locations in openings and under the forest-canopy. The study was started in July, 1940, and continued until October, 1941. Whenever possible rainfall was measured after each storm; observations were recorded in inches of water.

The study was designed for analysis by the covariance-method as outlined by SNEDECOR [5]. In one phase of the analysis only seasonal total gross and net rainfall were used to learn whether net rainfall differed between watersheds or between seasons. The results were divided into three six-month periods, roughly including the seasons characterized by either rain or snow, namely, the summer periods of 1940 and 1941 (April through September), and the winter of 1940-41 (October through March). In a second phase of the analysis 13 storms were selected at random from the total available storms for each season. As this analysis was made primarily to determine the relation between gross and net rainfall for individual storms it was necessary to eliminate all observations which included more than one storm. During the summer season of 1940 only 13 storms met this requirement, so the same number of storms was selected from each of the other two seasons.

In both sets of covariance-calculations, the purpose of analysis was only to learn whether the adjusted net rainfall varied among the three watersheds, and whether there was a significant variation between seasons. No attempt can be made to estimate interception-effects in other watersheds, since the areas studied are by no means a random sample of the entire ponderosa-pine type. Accordingly the variance within watersheds was the appropriate error term for testing the comparison between watersheds; and the interaction of "season" and "within watersheds" was used for testing the comparison between seasons and the interaction of watersheds and seasons.

Results

Seasonal total gross and net rainfall--During the course of the study 140 storms occurred which were used to make up the seasonal totals of gross and net rainfall (Table 1). These data show that by far the greatest number of storms occurred during the summer season of 1941. In general, rainfall in the summer of 1940 was approximately average in amount and character, followed by a rather dry and open winter; and the summer season of 1941 was above average in both number of storms and amount of rainfall. With approximately the same total precipitation on all watersheds, there was over three inches more net precipitation on watershed "B" than occurred on the other two areas. Averaging the three watersheds, 81.4 per cent of the total precipitation reached the ground under the forest-canopy.

Although net precipitation varied greatly among the three seasons, analysis of covariance (Table 2) showed that this fluctuation was entirely a function of gross precipitation; no significant difference remained between seasons after adjustment to the average gross precipitation

Table 1--Total seasonal gross and net rainfall by watersheds

Season	Number of storms	Watersheds						Average		
		B		C		E				
		Gross	Net	Gross	Net	Gross	Net	Gross	Net	Per cent[b]
		in	in	in	in	in	in	in	in	
Summer, 1940	25	4.61[a]	3.89	4.54	3.66	4.81	3.79	4.65	3.78	81.3
Winter, 1940-41	27	2.68	2.07	2.77	1.92	2.93	1.87	2.79	1.95	69.9
Summer, 1941	88	15.38	14.98	15.89	12.14	14.98	11.53	15.42	12.88	83.5

[a]Each entry is the average of records at six gages.

[b]Net precipitation expressed as percentage of gross.

Table 2--Covariance analysis of total seasonal net rainfall

Source	(D/F)	r^2	Mean square (errors of estimate)
Total	52	0.9214	2.0313
Between means of			
(1) Watersheds	2	....	8.8974[a]
(2) Seasons	2	....	0.2441
Interaction (1) × (2)	4	....	5.7390[b]
(3) Within watersheds (error for watersheds)	14	0.0526	2.2433
Interaction (2) × (3) [Error for seasons and (1) × (2) interaction]	29	0.0816	1.1088

[a]Significant ($p. < 0.05$). [b]Highly significant ($p. < 0.01$).

Table 3--Covariance analysis of net rainfall in individual storms (for determination of errors)

Source	(D/F)	r^2	Mean square
Between means of			
(1) Watersheds	2	....	0.1278
(2) Seasons	2	....	0.0198
Interaction (1) × (2)	4	....	0.0197[a]
Between locations within watersheds[b]	14	....	0.0497
Interaction (seasons × locations[c] within watersheds)	29	....	0.0072
Between storms within locations and seasons	647	0.8598	0.0155

Regression-formulas for each watershed:

Watershed "B" - $E = 1.2478x - 0.0626$; $r^2 = 0.8804$

"C" - $E = 0.9379x - 0.0423$; $r^2 = 0.9622$

"E" - $E = 0.8879x - 0.0217$; $r^2 = 0.9241$

[a]Significant ($p. \leq 0.05$). [b]Error for testing "watersheds". [c]Error for testing "seasons", "watersheds × seasons", and "locations within watersheds".

($F = (0.2441/1.1088)$ = less than unity). The excess of net precipitation for watershed "B" over the other watersheds was significant; also, the three watersheds seemed to respond differently to the same total rainfall in different seasons, as indicated by the significant interaction of watersheds with seasons.

Gross and net rainfall from individual storms--The effect of gross rainfall per storm on the amount actually reaching the forest-floor under a crown-canopy was determined on the basis of 13 storms selected at random from each of the three seasons. Analysis of these data (Table 3) reveals the degree of this association and provides a regression-formula for each watershed, from which net rainfall can be predicted for storms of various sizes.

As compared to the analysis of seasonal totals, the adjusted variance between seasons was not quite significant, and the watersheds did not differ significantly. The interaction of watersheds and seasons was barely significant. The results of both analyses indicate that there may be some real variation in net rainfall between watersheds, perhaps because of differences in the forest-canopy. Thus it would not be safe to use the average of the rain-gages in all three watersheds, or to use a single regression-formula, in computing the average net rainfall on a single watershed in any given storm.

The net rainfall on each watershed in single storms can be computed from the regression-formulas in Table 3. By inspection of these formulas it can be seen that the initial storage of the forest-canopy on these watersheds is about 0.03 to 0.05 inch, and that after the crowns have been saturated by initial storage practically all of the rainfall reaches the ground.

Conclusions

The following summarized conclusions can be drawn from the results of this experiment:

(1) On these watersheds an average of 81.4 per cent of the total precipitation reached the ground under tree-crowns. This amount varied significantly among the watersheds, probably because of a variation in density of the crown-canopies.

(2) About 0.03 to 0.05 inch of precipitation is required to saturate the forest-canopy in each storm. After this initial storage is filled, practically all of the rainfall reaches the ground.

(3) After adjustment to values expected for the average gross precipitation, there was no significant difference in net precipitation among the three seasons studied. Apparently the interception of snow by tree-crowns is quite similar in magnitude to the interception of rain; at least in this cover-type and climate.

References

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DISCUSSION

H. F. MOREY (Allegheny Forest Experiment Station, U. S. Forest Service, Philadelphia, Pennsylvania; communicated)--This paper is a contribution to hydrological knowledge in that it shows that the interception of precipitation may vary within watersheds of the same cover-type. The author states that this may be due to "variation in density of the crown-canopies." No doubt he will investigate the crown-densities of the three watersheds so as to check the assumption of crown-density variance.

Observations made by the discusser during April, 1942, in central Vermont indicate that a correlation may exist between the degree of interception and crown-density, stem-density, and stem-size. Coniferous stands above sapling-size that are very dense generally have thin crown-canopies, although the canopy may be complete. On the other hand, stands of the same species and size that are less dense may have a thick as well as a complete crown-canopy. There appears to be more snow-interception in the latter than in the former stands. Even small holes in the canopy will allow a greater accumulation of snow within the stand than a solid canopy. It has been observed that dense stands of hardwood-reproduction of three inches or less in diameter intercept less snow than stands in which the individuals are larger. The degree of interception also depends upon the understory. If shrubs are present within the stand, or a two-story forest exists, the degree of interception will be greater than if the stand has but a single story. Each type of vegetal cover appears to be limited as to the amount of precipitation it can intercept. Heavy accumulations of snow are blown off more readily than light ones. On the other hand, wet snow sticks better than dry snow, and sleet adheres better than rain. Due to these conditions, a straight percentage-factor cannot be applied with a high degree of accuracy for the determination of the amount of interception. Each type of storm should be treated individually and should not be grouped.

The author's figures of 0.03- to 0.05-inch interception per storm are believed to be too conservative for snow in the Upper Connecticut Valley. The interception--measured after the snow had blown from the crowns--during a storm which occurred on April 11, 1942, in Central Vermont was 0.08 and 0.36 inch of water, respectively, in fully stocked 60-year northern hardwood and 30-year red-spruce. The amount of water which fell in the open was 0.82 inch. The interception for fully stocked pine of similar size would have been somewhere between that of the spruce and hardwood.