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Interception by Eastern White Pine

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Abstract. Measurements of gross rainfall, throughfall, stemflow, and litter interception in three eastern white pine stands, age 10, 35, and 60 years, in the Southern Appalachians of western North Carolina, were used to derive regression equations for estimating throughfall, stemflow, and the sum of throughfall and stemflow from measurements of gross rainfall. Equations for total interception loss were derived by algebraically combining losses from the canopy and litter. These equations were used to predict total seasonal interception loss (I) from measurements of total seasonal rainfall (ΣP) and number of storms (N). Equations for the 10-, 35-, and 60-year-old stands are $I = 0.05(N) + 0.08\ (\Sigma P)$, $I = 0.05(N) + 0.12(\Sigma P)$, and $I = 0.06(N) + 0.18(\Sigma P)$, respectively. Total interception loss in white pine increased with stand age, and total loss from all pine stands studied exceeded losses calculated for mature hardwoods. During the dormant season, calculated monthly interception loss from mature hardwoods and white pine exceeded potential evapotranspiration calculated by the Thornthwaite method. (Key words: Interception; vegetation; water balance; evapotranspiration)

Eastern white pine (*Pinus strobus L.*) is an important coniferous species of eastern United States. Mixed hardwood stands sometimes are converted to pine, and it is often planted on reservoir headwater areas to prevent erosion. The effect on water yield of converting hardwood stands to pine is unknown. Although no one has conclusively shown that pine and hardwoods differ in annual water use, there are physical and physiological reasons for suspecting that pine uses more water than hardwood [*Hewlett,* 1958]. Pine, for example, retains its needles and can transpire water long after hardwoods have lost their leaves. Also, pine and hardwood may not intercept equal amounts of water. If a difference in evapotranspiration does exist, this can have an important bearing on management of lands supplying water for municipal, industrial, and agricultural purposes.

The role of interception in the water balance of forested catchments is not clearly understood. Proponents of the energy balance reason that interception and transpiration loss are compensating, because energy used to evaporate intercepted water is not available for other evaporative processes. Thus, evaporation of intercepted water results in a lower transpiration rate, and interception is not a loss additive to normal transpiration [*Burgy and Pomeroy,* 1958; *Leyton and Carlisle,* 1959; *McMillan and Burgy,* 1960]. However, *Goodell* [1963] and *Rutter* [1963] suggest that the sources of energy for transpiration and evaporation of intercepted water may not be the same; i.e., energy available for evaporation of intercepted water may exceed that available for transpiration. Indeed, interception losses calculated by *Patric* [1966] and *Rutter* [1963] indicated greater dormant season interception loss than could be explained by empirical formulas.

An exhaustive review by *Helvey and Patric* [1965*a*] established that interception loss from mature hardwoods was similar throughout the eastern hardwood region. Although interception by white pine has been studied [*Beall,* 1934; *Horton,* 1919], the reports are fragmentary, and results are not directly comparable with equations presented by Helvey and Patric. Therefore, between December 1964 and December 1965, a study was conducted to (1) measure interception loss by white pine, and (2) compare interception losses from eastern white pine with losses expected from mixed hardwoods for climate conditions prevailing in the vicinity of the Coweeta Hydrologic Laboratory near Franklin, North Carolina.

STUDY SITE

Three white pine stands in private ownership about 3 miles east of Highlands, North Carolina, were selected for study. Table 1 lists some stand characteristics. The 10-year-old stand is a dense plantation (7- by 7-foot spacing) about 3 acres in size. It is surrounded by a scattered to dense hardwood-pine forest, except for a 0.10-acre garden patch on the east side. The older pine stands are contiguous and became established on abandoned farmland. This 15- to 20-acre pine forest is bounded on the south by a 6-acre field, on the east by a 6-year-old pine plantation, and on the north and west by a hardwood forest. None of the stands has been disturbed by fire, but the basal area of the 35-year-old stand was reduced by about 25% during a thinning approximately 5 years before the study began.

METHODS

Gross rainfall, throughfall, stemflow, and litter interception were sampled as recommended by *Helvey and Patric* [1965*b*]. Gross rainfall was measured with U. S. Weather Bureau standard 8-inch gages located in clearings, one on either side of each stand.

Throughfall was sampled on 0.1-acre plots. Initially, 15 gages were used in each stand, but throughfall variance in the young plantation was higher than expected. To hold the standard error of throughfall measurements to 5%, 20 gages were used in this stand, but 15 were sufficient in the two older stands. All gages were located at random within one plot and were moved to a new plot at monthly intervals. Basal area and tree stocking were measured on each throughfall plot.

TABLE 1. Characteristics of Highlands, North Carolina, White Pine Stands

Stand Age, years	Average Basal Area, ft²/acre	Average Stocking, stems/acre	Average Height, feet
10	76	800	20
35	120	280	57
60	153	135	74

Stemflow was collected on 5 randomly located 0.01-acre plots in each stand. Collars attached to stems about 3 feet above ground level deflected stemflow from all trees within each plot through rubber tubes and into centrally located barrels for measurement. Stemflow was expressed as inches of water distributed uniformly over the plot. Because of the high cost of instrumenting stemflow plots, these plots were used throughout the study.

Throughfall (T), stemflow (S), and throughfall plus stemflow ($T + S$) data were analyzed by computer. Each of these dependent variables was assumed to be a linear function of gross rainfall, season (expressed as mean air temperature in degrees F on the storm date), average rainfall intensity, basal area per plot, and number of trees per plot. Two types of regressions were run: first, all measurements for the three stands were combined into a single regression; second, individual regressions for each stand were computed and tested by covariance techniques to determine if they were significantly different from the average equation (95% confidence). Data from 80 storms ranging from 0.02 to 2.85 inches in size were used in the analysis. Storms with snow were not used, and a few storms were discarded because of incomplete data.

Twelve litter samples, each 2 feet square, were collected from each stand at selected time intervals [*Helvey*, 1964] after rainfall to establish maximum and minimum field moisture contents and the drying rate of litter under natural conditions. These relations, along with rainfall patterns, were used to estimate litter interception loss.

RESULTS AND DISCUSSION

The covariance test showed that throughfall, stemflow, and the sum of throughfall and stemflow were each significantly different between stands. Gross rainfall (P) and average temperature on the storm date (D) were the only independent variables significantly related to the dependent variable. However, comparison of the correlation coefficients showed that gross rainfall explained most of the variation in throughfall, stemflow, and throughfall plus stemflow. To show a temperature (seasonal) effect, the multiple regression b coefficients must be carried to four decimal places. Since rainfall

TABLE 2. Equations for Estimating Throughfall, Stemflow, and Throughfall Plus Stemflow in Three White Pine Stands from Measurements of Gross Rainfall

Dependent Variable	Stand Age	Regression	Standard Error of Estimate
Throughfall	10	$T = -0.05 + 0.85P$	0.04
	35	$T = -0.04 + 0.85P$	0.05
	60	$T = -0.05 + 0.83P$	0.04
Stemflow	10	$S = 0.00 + 0.09P$	0.02
	35	$S = -0.01 + 0.06P$	0.01
	60	$S = -0.01 + 0.03P$	0.01
Throughfall plus Stemflow	10	$T + S = -0.05 + 0.94P$	0.05
	35	$T + S = -0.05 + 0.91P$	0.05
	60	$T + S = -0.06 + 0.86P$	0.04

measurements are only accurate to 0.01 inch at the very best, there is no advantage in including the temperature variable. Therefore, simple regression equations without the temperature variable were computed and are presented in Table 2. These equations can be used for computing interception for individual storms.

Throughfall and Stemflow

Throughfall in the 35-year-old stand slightly exceeded that in the 10-year-old stand, possibly a lingering effect of thinning 5 years earlier. However, there appears to be a negative correlation between throughfall and stand age, because measured throughfall was 2.7% less in the 60-year-old stand than in the young plantation. The amount of rainfall required to produce measurable throughfall was 0.06 inch for the 10- and 60-year-old stands and 0.04 inch for the 35-year-old stand.

Studies by *Beall* [1934], *Hoppe* [1896], and *Reynolds and Leyton* [1963] showed that throughfall distribution under forest trees varied directly with distance from tree trunks, but *Stout and McMahon* [1961] were unable to detect such a correlation. In this study, point throughfall tended to increase directly with distance from the tree in the 35- and 60-year-old stands (correlation coefficients 0.28 and 0.57 respectively), but there was no such correlation in the young plantation, probably because of overlapping crowns.

Stemflow varied inversely with stand age. Measured stemflow was 8.8, 4.3, and 2.3% of gross rainfall in the 10-, 35-, and 60-year-old stands, respectively. Although stemflow per storm decreased with stand age, the amount of rainfall required to cause measurable stemflow increased with age. Approximately 0.01 inch of rain caused water to flow down stems of the 10-year-old pine, but stemflow did not begin in the 60-year-old stand until 0.25 inch of rain had fallen. The upright branching habit and smooth bark of the young white pine provide efficient pathways for water flow, whereas wa-

TABLE 3. Equations for Computing Seasonal Interception Loss (ΣI) from Measurements of Total Rainfall (ΣP) and Number of Storms (N)*
(Equations for hardwoods are from Table 5, *Helvey and Patric* [1965*a*].)

Species	Age	Season	Equation
Mixed hardwoods	Mature	Growing	$\Sigma I = 0.04(N) + 0.08(\Sigma P)$
Mixed hardwoods	Mature	Dormant	$\Sigma I = 0.02(N) + 0.06(\Sigma P)$
White pine	10 years	Annual	$\Sigma I = 0.05(N) + 0.08(\Sigma P)$
White pine	35 years	Annual	$\Sigma I = 0.05(N) + 0.12(\Sigma P)$
White pine	60 years	Annual	$\Sigma I = 0.06(N) + 0.18(\Sigma P)$

* Because all rainfall in storms smaller than the *a* coefficients is lost by interception, these small storms are not included in the *N* value.

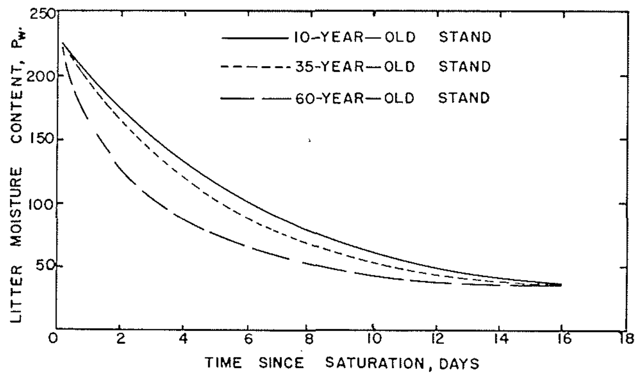

Fig. 1. Moisture content of the forest floor in three white pine stands as a function of time since saturation.

ter absorption by deeply fissured bark and increased drip from horizontal to slightly pendant branches of older trees appears to reduce stemflow.

Stemflow plus throughfall equations in Table 3 provide estimates of water reaching the forest floor. For the storms sampled, throughfall plus stemflow was 86, 84, and 77% of gross rainfall in the 10-, 35-, and 60-year-old stands, respectively. These equations show that, as well stocked eastern white pine matures, less water is delivered to the forest floor, and a greater percentage of rainfall is retained on and evaporated from the aerial parts of the tree.

Litter Interception

Water reaching the forest floor must pass through the litter layer to reach mineral soil. Thus, evaporation of water absorbed by litter must be considered in any complete interception study. Litter interception loss is a function of litter weight per unit area, its water holding characteristics, and the wetting frequency and the rate of drying [*Helvey*, 1964].

Litter weight beneath all three stands was about 5 tons per acre. The litter layer in all stands held about 230% (0.10 inch) moisture by weight at maximum and 40% (0.02 inch) at minimum water contents. Approximately 1 inch of throughfall was required to raise litter water content from 40% to saturation. Evaporation from the litter was initially most rapid beneath the 60-year-old stand and least rapid beneath the young plantation (Figure 1), but all stands reached minimum water contents at about the same time (16 days). The difference in drying rate presumably reflects differences in energy available to evaporate water and in air circulation beneath the stands.

Table 4 shows that, during the study period, litter interception loss from the older stands was almost double the loss from the young plantation. Although litter interception loss is only 2 to 4% of gross rainfall, it represented about 10% of the total interception loss from these stands.

Total Interception Loss

Equations for estimating seasonal or annual interception loss from canopy and litter were calculated by adding litter interception loss, expressed as a per cent of rainfall, to the complement of the throughfall plus stemflow equations listed in Table 2. Equations for eastern white pine and those derived for mixed hardwoods by *Helvey and Patric* [1965*a*] are presented in Table 3. These equations were used to compute interception loss for climatic conditions at the Coweeta Hydrologic Laboratory, where, for 20 years, an average of 128 separate storms delivered 80 inches of rainfall each year.

TABLE 4. Litter Interception Loss as Related to Stand Age

Stand Age (years)	Litter Interception Loss (inches)	Litter Interception Loss (% of P)
10	1.2	2
35	1.8	3
60	2.2	4

TABLE 5. Comparison of Computed Annual Interception Losses from Eastern White Pine and Mixed Hardwoods under Average Climatic Conditions Prevailing at the Coweeta Hydrologic Laboratory

Species	Age	Annual Interception Loss	
		Inches	% of *P*
Mixed hardwoods	Mature	10	12
White pine	10	12	15
White pine	35	15	19
White pine	60	21	26

On the average, 28 of these storms were smaller than 0.05 inch and delivered 0.60 inch of rainfall annually. Estimated annual interception losses for these conditions are presented in Table 5.

During summer months, interception loss from the 10-year-old plantation is slightly greater than that estimated for mature hardwoods, and, on an annual basis, interception by young pine is over 2 inches more than by mixed hardwoods. Interception losses in 35- and 60-year-old white pine exceeded losses in hardwood during both the growing and the dormant season. Annually, 60-year-old white pine intercepts twice as much water as hardwoods. These results suggest that over ¼ of the rain falling on the 60-year-old white pine was returned to the atmosphere without reaching mineral soil.

Potential evapotranspiration calculated by the *Thornthwaite* [1954] method averages 27.5 inches annually at Coweeta. As a percentage of annual potential evapotranspiration, interception loss varies from about 36% for hardwoods to about 76% for old growth white pine stands. However, when interception loss as a percentage of potential evapotranspiration is plotted on a monthly basis (Figure 2), seasonal differences are obvious. For a given stand, interception loss from May through September is a fairly consistent percentage of potential evapotranspiration. It is also apparent from Figure 2 that evaporation of intercepted water during winter months greatly exceeds that estimated by empirical formula. The greatest difference occurs in December, when the estimated interception losses from hardwoods and 60-year-old white pine are 190 and 560% of potential evapotranspiration, respectively. These large ratios during winter months are consistent with findings by *Patric* [1966] and *Rutter* [1963]. Data in *Rutter*'s [1963] Table 4 provide a comparison to the relations in Figure 2. His ratios of

$$\left(\frac{\text{interception}}{\text{theoretical evaporation}}\right)$$

for November, December, and January are 4.24, 5.16, and 4.69, respectively. (Theoretical evaporation is the Penman estimate of open water evaporation.) Thus, evidence is accumulating that empirical methods of estimating evaporation loss during winter months may grossly underestimate possible evaporation of intercepted water from forest stands.

The estimates of interception loss are derived from average equations for many hardwood stands, but for only three white pine stands in one general location. Thus, the comparisons presented in Figure 2 and Table 5 must be regarded as approximations, even for Coweeta's climate. Interception by other stands will vary somewhat from results presented here, depending on stand characteristics and climatic conditions. Since annual rainfall and number of storms are greater in the study area than in most regions of the East, these data represent maximum probable differences that can be expected. However, even small interception differences between conifers and hardwoods may assume importance in regions of low rainfall, simply because less water is available in those areas.

Although calculated interception loss from 60-year-old white pine was about 11 inches more than from mature hardwoods, this does not necessarily mean that watersheds converted from hardwood to white pine will yield 11 inches less water when the pines are mature. We still do not know whether evaporation of intercepted water is offset exactly by a reduction in transpiration, or whether total annual evapotranspiration losses from white pine and mixed hardwood stands differ. Final proof of a difference in water yield after converting hardwood stands to white pine must await testing on carefully controlled experimental watersheds. Two such long-term experiments are under way at Coweeta, but the final results are not expected for perhaps 30 years. Meanwhile, this study has shown that interception loss from

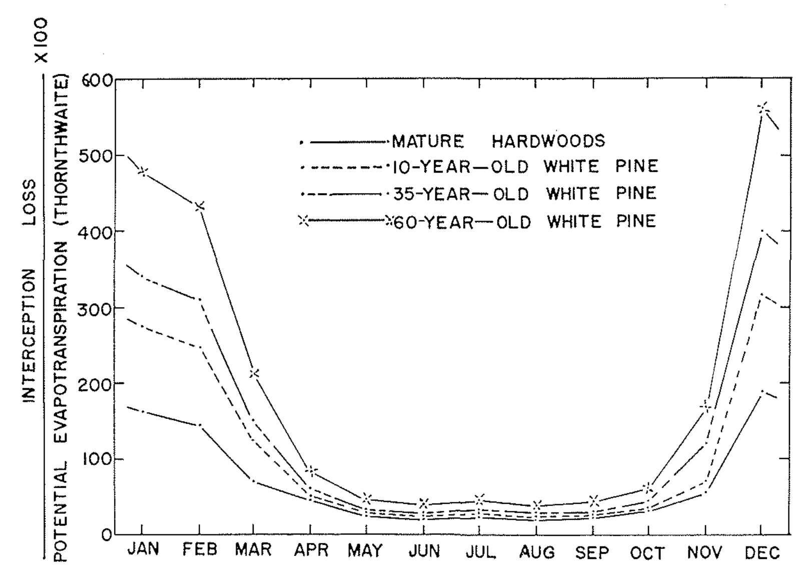

Fig. 2. Average monthly interception loss as a per cent of potential evapotranspiration at Coweeta.

white pine exceeds loss from mixed hardwoods, and these differences could have a substantial effect on streamflow.

SUMMARY

Total interception loss of three white pine stands growing in the Southern Appalachian Mountains was related to age of the stand. It was found that the older the stand the greater the loss. Comparison of estimated interception losses under climatic conditions prevailing in the mountains of western North Carolina indicate that interception loss from old growth white pine may be as much as 100% greater than loss from hardwoods. Results also indicate that during winter months, interception loss from pine and hardwood greatly exceeds potential evapotranspiration calculated by the Thornthwaite method.

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