Interception loss in loblolly pine stands of the South Carolina Piedmont

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ABSTRACT—Annual interception loss was measured in 5-, 10-, 20-, and 30-year-old loblolly pine stands and in a mature hardwood-pine forest in the Piedmont of South Carolina. Interception loss for the loblolly pine stands was estimated to be 14, 22, 18, and 18 percent of annual precipitation (54 inches). Annual interception loss from the hardwood-pine stand was similar to that of the pine stands. However, on the average, the loss of water intercepted annually by loblolly pine appeared to be about 4 inches greater than the loss estimated from a number of hardwood studies. Where extensive conversions of hardwood to loblolly pine occur, significant reductions in the amount of water available for streamflow or groundwater should be expected.

LOSS of intercepted rainfall in forests ranges from 10 to 35 percent of annual precipitation and, therefore, represents an important component in the water balance of forested watersheds. Recent studies at the Coweeta Hydrologic Laboratory in North Carolina demonstrate conclusively that conversion of watersheds from mature mixed hardwoods to young white pine substantially lowers streamflow (*14*). For example, in 1970 streamflow from a 14-year-old white pine stand on a 40-acre watershed was reduced 7 area-inches (8 million gallons per year) below the flow expected from the original hardwood forest on the watershed. Such reductions are partly attributable to greater interception loss from white pine than from hardwoods (*14*).

These studies have led to questions concerning interception differences between hardwoods and coniferous species and to the effects of these differences on water resources. Such questions are indeed pertinent in the southern United States where large areas are being converted from hardwoods to pine. In South Carolina's Piedmont region, a survey showed a 20-percent increase in pine and oak-pine cover types and a concurrent 17-percent decline in hardwood types between 1958 and 1967 (*2*). A similar trend in cover-type changes was documented in the state's Northern Coastal Plain during the same period (*17*). With increased emphasis on wood production from the South's Third Forest, it is estimated that 50 million acres of commercial forest land in the southern states are suitable for conversion from hardwoods to pine (*1*).

A review of interception studies for southern pine species suggests appreciably greater annual interception losses (3 to 4 inches) for mature loblolly and shortleaf pine than for mature mixed hardwoods; even young stands of these pine species tend to intercept more rainfall than do mature hardwoods (*13*). However, components of interception, such as stemflow and litter interception, were excluded from these studies, and a complete interception study has never been reported for southern pines. Therefore, a cooperative effort between the Forestry School at Clemson University and the Coweeta Hydrologic Laboratory was initiated in 1968 with the primary objective of documenting interception losses in four loblolly pine (*Pinus taeda* L.) stands of different ages and in one mature hardwood-pine stand.

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Study Area

The study area is located in Pickens and Anderson Counties, South Carolina. The upland hardwood-pine stand and the loblolly pine plantations selected are typical of forests found in the upper Piedmont.

The overstory of the hardwood-pine stand is composed principally of oaks (*Quercus* spp.), hickories (*Carya* spp.), and shortleaf pine (*Pinus echinata* Mill.). Pine accounted for 14 percent of the total basal area of the stand in the study plots. The understory, in addition to the foregoing species, contained flowering dogwood (*Cornus florida* L.), sourwood [*Oxydendrum arboreum* (L.) DC.], and black gum (*Nyssa sylvatica* Marsh.). Despite a large volume of mature hardwood and pine, no cutting has taken place over the past 20 to 25 years because the stand has been involved in a soil-site evaluation study.

The four loblolly pine plantations (identified as stands 1 through 4) represent age classes of 5, 10, 20, and 30 years (Table 1). The 5-year-old stand was established on pasture seeded to fescue and grazed 8 to 10 years prior to pine establishment. The area was machine-planted with 1-0 loblolly pine seedlings at 6-foot by 6-foot spacing. Survival was about 92 percent. The three older pine plantations, established on abandoned agricultural land, were hand-planted with 1-0 loblolly pine seedlings at 6-foot by 8-foot spacing. Survival was 80 to 85 percent. The oldest plantation was commercially thinned at 15 and 22 years. The other plantations are unthinned, although natural mortality has substantially reduced the density of the 20-year-old stand. Understory vegetation is sparse, with only scattered stems of advanced hardwood reproduction in the 20- and 30-year-old stands. Because fire is excluded from the stands, litter is abundant.

Preciptation in the study area averages 51 inches a year. It is generally distributed uniformly by months but may be variable in any given year. Dry periods usually occur in June, October, and November. Maximum temperatures average 72°F; minimums average 48°F. The mean annual temperature is 61°F.

Experimental Design

Experimental procedures followed the design criteria for interception studies recommended by Helvey and Patric (*6*). Gross rainfall was sampled in standard 8-inch Weather Bureau gages located at 45° openings adjacent to the forest stands. Gross precipitation (P) was sampled at two or three locations for each stand, and three recording rain gages in the vicinity of the study sites provided data on storm separation and rainfall intensity. Throughfall was sampled in each stand by randomly locating fifteen 8-inch gages in a 0.1-acre plot; 20 gages were used in the youngest pine stand to compensate for the large variability in throughfall. New 0.1-acre plots were established at monthly intervals when gages were moved to new random locations.

Stemflow was measured on all trees growing on five circular 0.01-acre plots in each stand. These randomly located plots were not changed throughout the study. A total of 44, 51, 33, 14, and 35 trees were used in stemflow measurements in stands 1 through 5. A collar fitted to each tree drained stemflow to barrels.

Fifteen litter samples, each 2 feet square, were collected each time throughfall gages were moved to new locations to determine litter accumulations during the study. Because of insignificant quantities of litter, samples were not collected in the 5-year-old loblolly pine stand. Litter samples also were collected at irregular intervals to establish average wetting and drying rates (*3*).

Data on gross precipitation, throughfall, and stemflow were collected at each study site following a storm. A storm was defined as a period of precipitation separated by 6 hours or more with no measurable rainfall. Measured stemflow volumes were converted to inches of water over the plots. On each plot where throughfall and stemflow were recorded, basal area at breast height and number of trees were tallied for correlation with throughfall and stemflow.

Data on throughfall (T), stemflow (S), and throughfall plus stemflow (T+S) were calculated for each stand. Each of these dependent variables was analyzed in a multiple linear regression in which the independent variables were gross rainfall, plot basal area, growing and dormant season (expressed as a sine function), and an interaction function derived by multiplying gross precipitation by the sine value. The purpose of the interaction was to determine whether a given amount of rain would produce the same amount of throughfall or stemflow at all times of the year. Data from 46 storms ranging in size from 0.06 to 5.13 inches were used for stands 2, 3, and 4. Data from an additional 10 storms were collected from stands 1 and 5 because of their greater variability in throughfall. Measurements began on October 6, 1968, and ended on January 26, 1970.

Results and Discussion

The multiple linear regression analysis showed that gross rainfall accounted for 98 to 99 percent of the variation in throughfall in each stand and that the second most important variable changed from stand to stand. Gross rainfall alone accounted for 85 to 90 percent of the variation in stemflow, and the gross rainfall-sine interaction removed an additional 1 to 4 percent of the variation in four stands. The interaction indicated that a given rainstorm produces slightly more stemflow during the dormant season than during the growing season. However, when throughfall and stemflow were combined, the second variable again was inconsistent among stands, that is, it contributed little toward improving the precision of the regressions. Since there was little advantage to including a second independent variable, simple regression equations with gross precipitation as the only independent variable were derived (Table 2). These equations can be used to compute components of the interception process for individual storms.

Throughfall and Stemflow

Although average basal area was greatest in stand 4, past thinnings had left numerous openings in the forest canopy. It was not surprising then that throughfall was highest (85 percent of gross precipitation for a 1-inch storm) in this oldest pine stand. Average throughfall for the other four stands was 0.85P for mature hardwoods, 0.80P for 5-year-old pine, 0.77P for 20-year-old pine, and 0.73P for 10-year-old pine.

Rogerson (*12*) found that throughfall in loblolly pine stands decreased as stand basal area increased. When his equations for estimating throughfall from gross precipitation and basal area were applied to our stands, throughfall was overestimated by 20 percent for stand 2, but estimates were close to measured values in the oldest stand (stand 4). A study of throughfall in four loblolly pine stands

Table 1. Stand characteristics based on 10 interception plots (0.2 acre each) for each study site.

Stand No. and Species	*Age (yr)*	*Total Height (ft)*	*Average Basal Area (ft^2/a)*	*Basal Area Range (ft^2/a)*	*Average Stocking (stems/a)*	*Stocking Range (stems/a)*
1. Loblolly pine	5	15	65	40- 89	889	730-1,120
2. Loblolly pine	10	38	110	100-136	1,053	970-1,190
3. Loblolly pine	20	62	138	116-175	622	530- 720
4. Loblolly pine	30	71	152	115-188	362	250- 580
5. Hardwood-pine	Mature	Multistoried	94	75-111	716	520- 900

Table 2. Equations for estimating throughfall, stemflow, and throughfall plus stemflow in four loblolly pine stands and one hardwood-pine stand from measurements of gross rainfall.

Dependent Variable	*Stand No. and Species*	*Age (yr)*	*Regression*	*Sy.x*
Throughfall (T)	1. Pine	5	T = −0.03 + 0.83P	0.13
	2. Pine	10	T = 0.00 + 0.73P	0.09
	3. Pine	20	T = 0.01 + 0.76P	0.07
	4. Pine	30	T = 0.00 + 0.85P	0.09
	5. Hardwood-pine	Mature	T = −0.02 + 0.87P	0.07
Stemflow (S)	1. Pine	5	S = −0.01 + 0.09P	0.03
	2. Pine	10	S = −0.02 + 0.11P	0.04
	3. Pine	20	S = −0.03 + 0.12P	0.06
	4. Pine	30	S = −0.02 + 0.04P	0.02
	5. Hardwood-pine	Mature	S = −0.01 + 0.03P	0.02
Throughfall plus stemflow (T+S)	1. Pine	5	T+S = −0.04 + 0.92P	0.11
	2. Pine	10	T+S = −0.02 + 0.84P	0.10
	3. Pine	20	T+S = −0.02 + 0.88P	0.08
	4. Pine	30	T+S = −0.02 + 0.89P	0.09
	5. Hardwood-pine	Mature	T+S = −0.03 + 0.90P	0.07

(ages 25 to 35 years) in the Piedmont of North Carolina also gave a prediction equation similar to ours for stand 4.[1] An interception study in eastern white pine showed that throughfall tended to decrease as stand age increased (*4*). However, information about the amount and distribution of intercepting plant surfaces which allow rainfall to pass to the forest floor is more closely related to interception processes than to basal area or stand age (*11*, *13*). Studies of biomass for loblolly pine indicate that stand foliage reaches a maximum at about 20 years of age, depending upon stocking and site quality (*15*). In our study, the level of stocking was greatest by far for the undisturbed 10-year-old stand; stocking in older stands with larger basal areas was reduced by thinning and mortality. Cultural practices that reduce stand canopy will increase throughfall (*16*); therefore, it was not surprising that throughfall was least in stand 2 and greatest in stand 4. The relation between throughfall and gross precipitation for stand 2 is nearly identical to the equation reported by Hoover (*7*) for a similar 10-year-old loblolly pine stand at Union, South Carolina.

In the hardwood stand, throughfall was below average values according to equations for the growing (87 percent) and dormant (90 percent) seasons derived by Helvey and Patric (*5*) for mature, mixed hardwood stands in the eastern United States, but results are well within the range of reported values. The insignificant differences in throughfall between the growing and dormant seasons in our study probably reflect the influence of the pine component in the hardwood stand.

Stemflow was a significant component of the interception process in all loblolly pine stands. In stands 1, 2, and 3, stemflow quantities were about equal (9 percent of gross precipitation). In stand 4 and the hardwood stand, stemflow was 2 percent of gross precipitation. Heretofore, stemflow in loblolly pine has been considered a minor component of the interception process. Our results indicate that studies which ignore stemflow will significantly overestimate interception loss. For example, in a region where annual rainfall is 50 inches, interception loss could be estimated about 4.5 inches too high if stemflow were not measured. Stemflow for the hardwood stand was slightly below amounts computed for eastern hardwoods (*5*), but it was almost identical to the average of the equations derived for the oak-hickory type. The average equation probably reflects the influence of northern hardwoods which have high stemflow values.

The amount of rainfall reaching the forest floor can be estimated from the equations for throughfall plus stemflow in table 2. Values are 88 percent of gross rainfall in stand 1, 82 percent in stand 2, 86 percent in stand 3, and 87 percent in stands 4 and 5. Thus, except for the 10-year-old loblolly pine stand, net rainfall differed little with stand age or composition.

Litter Interception

Although studies have shown that evaporation of water absorbed by litter is a significant component of interception, annual losses for loblolly pine have not been reported. The loss of water intercepted by litter can be considered as a function of accumulated weight of the litter per unit area, water retention characteristics of the litter, and its wetting frequency and drying rate (*3*).

On the basis of 24 collections from each stand during the period September 1968 to November 1969, the amount of accumulated litter varied widely within and between stands, depending upon time of year and stand age. The weight of loblolly pine litter increased with stand age, ranging between 4.0 and 5.1 tons per acre (Table 3). Litter amounts also varied annually, with a maximum weight occurring late in October and a minimum weight occurring in the middle of June for most stands. Stand 1 had no appreciable accumulation of litter. The average litter weight of 3.3 tons per acre for stand 5 is typical for hardwood stands elsewhere in the South Carolina Piedmont (*9*).

At field capacity, the litter for all stands retained about 210 percent moisture by weight. Minimum moisture content for all loblolly pine stands during the study was 20 percent. Drying curves for the litter in each stand were similar to the curve described by Metz (*10*). Minimum moisture content occurred about 8 days following saturation in stand 2, while drying was more rapid in stands 3 and 4 where equilibrium was reached in only 5 days. Approximately 1 inch of throughfall was required to raise moisture content from 20 percent to field capacity. Total interception loss by litter for the study period was calculated from records of the frequency and amounts of rainfall, litter weights, and drying curves (Table 3). Losses in loblolly pine were highest for the oldest stand, and losses exceeded 2 inches or 3 to 4 percent of gross rainfall for all loblolly pine stands. Loss of water intercepted by hardwood litter was only 0.6 inch less than the maximum loss for loblolly pine.

Total Interception Loss

All components of the interception process were combined, and equations for estimating total interception loss from gross rainfall and the number

Table 3. Average annual accumulation of litter and its interception loss in four loblolly pine stands and one hardwood-pine stand.

Stand No. and Species	*Age (yr)*	*Average Accumulated Litter (t/a)*	*Annual Litter Interception Loss (in)*	*(% of P)*
1. Pine	5	Insignificant	—	—
2. Pine	10	4.0	2.1	3
3. Pine	20	4.4	2.2	4
4. Pine	30	5.1	2.4	4
5. Hardwood-pine	Mature	3.3	1.8	3

Table 4. Equations for computing annual interception loss (I) in four loblolly pine stands and one hardwood-pine stand from measurements of total rainfall (P) and number of storms (N).

Stand No. and Species	*Equation*
1. Pine	$I = 0.04\ (N) + 0.08\ (P)$
2. Pine	$I = 0.02\ (N) + 0.19\ (P)$
3. Pine	$I = 0.02\ (N) + 0.15\ (P)$
4. Pine	$I = 0.02\ (N) + 0.15\ (P)$
5. Hardwood-pine	$I = 0.03\ (N) + 0.13\ (P)$

[1]Murphy, C. E., Jr. 1963. "The relationship of interception of precipitation to density in loblolly pine stands." Unpublished study report. Duke Univ., Durham, N. C. 90 pp.

of storms were calculated (Table 4). These equations were used to estimate annual interception loss based on the 45-year mean precipitation and storm frequency at Clemson, South Carolina (Table 5) (*8*). Included in table 5 for comparison are interception losses for three stands of eastern white pine and mature hardwoods (*4*, *5*). These comparisons also are based on precipitation characteristics at Clemson.

Annual interception loss was 11.7 inches (0.22P) in the 10-year-old loblolly pine stand. This was the largest loss for the sites in this study. Interception loss was only 7.3 inches (0.14P) in the youngest stand, while losses in the two oldest loblolly pine stands were 9.6 inches. These data suggest that interception losses increase as loblolly pine stands develop unless management practices reduce stocking and tree canopy. Under typical management practices or with natural mortality, interception loss tends to stabilize at about 10 inches. Thus, about equal amounts of rainfall reach the soil beneath managed loblolly and upland hardwood-pine forests because of similar interception losses.

On the other hand, the hardwood-pine data represent one specific set of forest conditions requiring an additional comparison of estimates of interception loss between cover types on the basis of the summary of 22 studies from hardwood stands in the East (*5*). These stands are probably more representative of the 80 million acres occupied by the oak-hickory type in the southern states than our hardwood-pine stand. Average annual interception loss for hardwood stands was calculated as 6 inches or 11 percent of gross precipitation (Table 5). Thus, on the average, annual interception loss from loblolly pine is expected to be 4 inches greater than from mixed hardwoods. A similar difference in interception loss between 35-year-old pine and hardwoods is shown in table 5.

Management Implications

Individual interception studies must to some extent be regarded as case histories for a specific set of stand and climatic conditions, and caution must be used when extending results from an individual study to other sites within a region. Nevertheless, the results of this study and other experiments in the Southeast, when taken collectively, permit us to draw some general conclusions useful to the water resource manager.

It is clear from watershed experiments (*14*) that increased interception loss occurs when hardwood-covered watersheds are converted to white pine, causing significant reductions in streamflow even when the pine forest is young and not fully developed. Other evidence indicates that interception loss from loblolly pine is substantially greater than from mixed hardwood forests and that losses from loblolly pine are at least equal to losses from immature white pine. It is reasonable, therefore, to expect that streamflow or groundwater supplies will be reduced in areas where the cover-type conversion is from oak-hickory to loblolly pine. In the vicinity of Clemson, for example, interception differences alone might well account for an average annual reduction of 4-area inches (109 million gallons) of water when a 1,000-acre watershed covered with oak-hickory is converted to loblolly pine. This represents an approximate streamflow reduction of 25 percent, a magnitude of change that warrants careful consideration.

We should also point out that transpiration losses are probably greater for pines before and during leafing-out of hardwoods; therefore, evapotranspiration differences between these two cover types may be much greater than those indicated by interception data alone. In hardwood stands where pine already comprises a significant part of the forest, the conversion to pure pine will probably have less effect on interception losses, and thus a smaller impact on water yield could be expected. Also, differences in interception loss between loblolly pine and hardwoods will be minimum for management situations where pruning or pre-commercial and commercial thinning are applied to the pine. Furthermore, a reduction in water yield equal to or greater than that suggested by this study could be expected on watersheds where agricultural land has been planted to pine.

On millions of acres in the South, contemplated conversion from hardwood to pine and trends toward reversion of agricultural lands to forests could have a significant impact on regional water supplies. It is beyond the scope of this paper to discuss the economic aspects of the production of wood versus water; economics is specific to a locality. However, the resource manager should recognize that in areas where the water supply is of primary concern any forest management practice that increases evapotranspiration and thereby lowers the amount of water available for streamflow and groundwater supplies may have important consequences.

Table 5. Annual interception loss based on rainfall characteristics at Clemson, South Carolina, as computed for the four loblolly pine stands and one hardwood-pine stand in the present study and also for white pine and mixed hardwoods.

Stand No. and Species	*Age (yr)*	*Annual Interception Loss*[a] *(in)*	*(% of P)*
1. Loblolly pine	5	7.3	14
2. Loblolly pine	10	11.7	22
3. Loblolly pine	20	9.6	18
4. Loblolly pine	30	9.6	18
5. Hardwood-pine	Mature	9.3	17
White pine[b]	10	8.1	15
White pine[b]	35	10.2	19
White pine[b]	60	14.2	26
Mixed hardwoods[c]	Mature	6.0	11

[a]Average annual precipitation for Clemson as reported by Kronberg et al. (*8*) is 53.9 inches delivered in 75 storms.
[b]Estimated from equations reported by Helvey (*4*).
[c]Estimated from equations reported by Helvey and Patric (*5*). Data from 22 studies of hardwood stands are summarized.

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