

Damage to Recently Thinned Loblolly Pine Stands

by Hurricane Donna

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Abstract. Hurricane damage was assessed by determining the percentage of trees injured by the storm. Stand and soil characteristics were determined. Tree damage was recorded separately for "main stem" (breakage) and for "root system" (displacement from original position or blowdown). Over 99 percent of damaged trees were of the second type. Stem breakage was insignificant. Damage was more severe on soils having moderately coarse textured profiles than on soils with finer textured profiles. It was most severe where restrictive layers occurred within the profile that tended to retard root and water penetration.

IN RECENT TIMES tropical hurricanes have struck repeatedly along the Gulf and Atlantic coasts, doing a tremendous damage to timber stands near the coast and less serious damage inland. Although all hurricanes on a grand scale are similar by definition, the kind of damage has varied. Observations indicate that the forest's location in relation to the storm's eye explains some of the variation in damage among stands. Within an individual stand, variation in damage has been correlated (8) with the size of the timber and the exposure of the trees to the wind.

Foresters and soil scientists believe that hurricane damage may also be associated with soil and timber stand characteristics. Hurricane Donna, which passed along the Atlantic coast in September 1960, provided an opportunity for study and the results are summarized in this paper.

The Storm

Tropical Hurricane Donna passed along the Atlantic coast of North Carolina and Virginia on September 11 and 12, 1960. The large eye (possibly the largest on record) was a continuing feature as Donna moved rapidly northeastward paralleling the Middle Atlantic coast during the morning hours of the 12th. A complete description of Hurricane Donna was obtained from the National Weather

Records Center of the U. S. Weather Bureau, at Asheville, N. C., and from local observations.

In North Carolina, sustained winds ranged from 53 mph at Wilmington to 83 mph at Elizabeth City. Gusts were measured or estimated in excess of 100 mph along the coast and at 80 to 90 mph along the path of the storm's center. In Virginia, sustained winds reached 80 mph at Cape Henry, and 75 mph at Norfolk, with gusts around 90 mph in the area under study.

Rainfall preceding and during the storm was heavy. For September 11 and 12 at Gatesville, N. C., 6.37 inches were recorded, and 6.17 inches for the same period at Holland, Va. At Como, N. C., 9.00 inches were recorded by the U. S. Forest Service. Heavy rainfall, a feature of this storm, set the stage for the type of damage sustained.

Rainfall pattern was similar at Wilmington, Hatteras, and Norfolk, beginning 19 to 20 hours prior to the storm passage, and with 12 to 22 percent of all rain falling in a 5- to 9-hour period. There followed a 3- to 4-hour period of no rain, and then 75 to 79 percent of the total storm's rain fell in a period of 7 to 11 hours immediately preceding the storm proper. Light rains continued for 2 or 3 hours after the storm had passed. The heaviest rainfall (over 1 inch per hour) occurred 2 to 4 hours prior to the time of maximum wind speeds.

The path of the storm's eye passed to the east of an eight-county area in which damage was studied (Fig. 1). Forest stands in-

cluded in this survey were distributed from the path of the eye of the storm to a distance of about 60 miles to the northwest.

Methods

Preliminary observations indicated that high winds did heavier damage in thinned stands than in unthinned stands. Therefore, only planted or natural loblolly pine stands that had been thinned during the preceding three years were included in this study. Of the 102 stands sampled, 92 originated from natural regeneration and 10 had been planted. All had been thinned by the Virginia Division of Forestry; the Union Bag-Camp Paper Corporation, Camp Division; or Weyerhaeuser Company, North Carolina Division.

Thinning varied from very light (thinnings from below) to heavy (crown thinnings designed to establish seed production areas). The density of each stand before wind damage was estimated and expressed in percent (%). It ranged from 20 to over 100 percent of full stocking. Most of the stands were between 40 and 70 percent stocked.

Average tree size varied from 6.1 inches d.b.h. in a young plantation to 15.0 inches in a natural stand of large sawtimber trees.

In each stand, tree damage was determined on enough 1/10-acre circular plots of uniform soil to obtain a sample of about 50 trees. In total, 314 of these circular plots were studied, including tallies of 4,796 trees. Each tree was classified as "undamaged," "damaged main stem," or "damaged root system." Damaged main stem referred to trees with broken stems. Dam-

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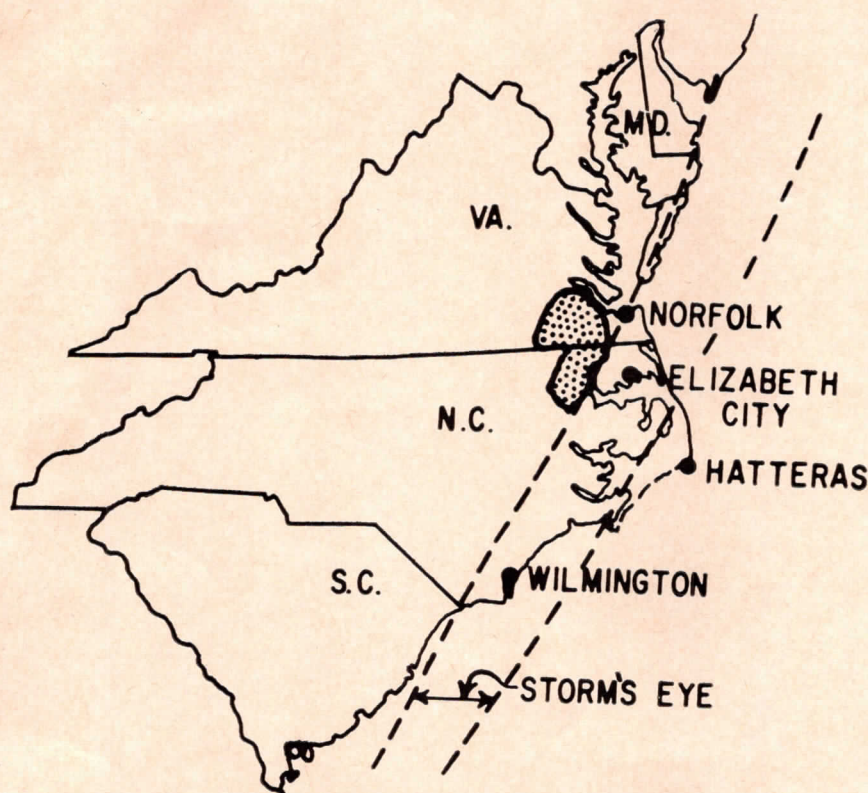


FIG. 1.—Path of tropical Hurricane Donna, showing location of the eight-county study area (shaded). This area extends approximately 60 miles to the northwest of the path of the hurricane.

aged root system included uprooted or leaning trees where roots had been displaced from their original position causing permanent injury. Only root damage is considered in this paper because main stem damage was insignificant (0.3 percent).

Soils on each of the 102 sampled stands were examined, classified, and named according to a national system used by the Soil Conservation Service (6). There were not enough samples on any of the named soils so that they could be studied individually. Soils were, therefore, grouped to facilitate study of the possible influences of certain major physical characteristics on wind damage. The first criterion for these groupings was the dominant textural class of the entire soil profile. Three such classes were used — moderately coarse textured profiles, medium textured profiles, and fine textured profiles. Within each of these groups, standard drainage classes were recorded for each soil. Field examinations showed that the soils on 16 of the study areas were not typical for the named series because their profiles showed a non-

typical layer of impervious material that acted as a barrier to the taproot and water penetration (Table 1). These layers were generally below the sola¹ and at depths of from 42 to 52 inches. Such layers tend to hold water within the soil layers above, causing "water-logging" or "super-saturation" during periods of heavy rainfall. The extent of such nontypical conditions is not known for the soils in question, but in a detailed soil survey they would be classified as "inclusions," or mapped as "phases," depending upon their continuity and extent.

None of the soil series studied had such restrictive layers in the typical profiles except the Atlee series, which may or may not have a thin restricting layer in the lower solum. However, none of the plots examined on Atlee soils had a layer that was classed as restrictive.

Wind damage may be related to many factors, among which are the

¹The sola may be defined simply as the genetic soil developed by soil-building forces. In normal soils, the sola includes the A and B horizons, or the upper part of the soil profile above the parent material (6).

characteristics of the stand or of the site: i.e., size of trees, density of stands, origin of stands such as planted or natural; dominant textural class of the soil profiles, soil drainage classes, presence or absence of restricting profile layers. Using a transformed expression of "percent of trees damaged" as the dependent variable, we made multiple regression analyses and chi-square statistical tests to determine the relative influence of some of these variables. The following results are based in part on these statistical interpretations of the data.

Results

Significantly greater wind damage occurred on soils with restrictive layers in the profile. Fifty-one percent of the trees on plots where soil profiles contained a restrictive layer in the profile were damaged, as compared with 7 percent on plots where soil profiles showed no restrictive layer.

In comparison with other soils sampled, wind damage was also significantly greater on soils with moderately coarse textured profiles. Approximately 30 percent of the trees on such profiles were damaged, as compared with only 5 percent on the medium and fine textured profiles.

Wind damage to planted stands was significantly less (but only at about the 10-percent level) than it was to naturally occurring stands. None of the other items tested proved to have any statistical significance in relation to wind damage.

There was no damage on 31 of the 102 stands studied, but at one location all trees were damaged. Some damaged trees remained standing, but root systems were displaced from original positions, causing serious permanent damage (Fig. 2).

Many of the damaged trees were completely toppled over. They fell in one of three ways: (1) The soil mass occupied by the root system was lifted as the tree fell, leaving a depression and adjacent root mound on the windward side of the fallen stem. This was the most common type of toppling noted. (2) Lateral roots on both sides and approximately at right angles to the direction of the wind did not

TABLE 1.—FREQUENCY OF SAMPLED STANDS BY SOIL SERIES, PROFILE TEXTURAL CLASSES, DRAINAGE CLASSES, TYPICAL, AND NONTYPICAL PROFILES

Soil series	Drainage class	Profile characteristic	
		Typical	Nontypical
Moderately coarse textured profiles			
		— Number of stands —	
Lakeland	Excessive	1	—
Lakeland (terrace phase)	Excessive	—	1
Norfolk (thick surface phase)	Well to excessive	12	6
Rumford (thick surface phase)	Well to excessive	1	—
Kalmia (thick surface phase)	Well to excessive	1	—
Norfolk	Well	4	4
Klej	Moderately well	1	—
Woodstown	Moderately well	5	—
Dragston	Somewhat poorly	1	—
	Subtotal	26	11
Medium textured profiles			
Marlboro	Well	3	—
Atlee	Moderately well	12	—
Goldsboro	Moderately well	4	1
Izagora ¹	Moderately well	6	—
Dunbar	Somewhat poorly	2	2
Lynchburg	Somewhat poorly	1	1
Othello	Poorly	4	—
	Subtotal	32	4
Fine textured profiles			
Craven-like ¹	Well	1	—
Craven	Moderately well	5	—
Lenoir	Somewhat poorly	6	1
Bladen	Poorly	3	—
Leaf	Poorly	1	—
Coxville	Poorly	11	—
Elkton	Poorly	1	—
	Subtotal	28	1
Total number of stands sampled		86	16

¹Uncorrelated soils.

fail. Trees toppled over in the direction away from the wind, pivoting on the roots that did not fail. The entire root system on the leeward side was forced into the soil as the tree toppled, forming a deep depression beneath the stump of the fallen tree (Fig. 3). Roots on the windward side failed under

tension but left little evidence of a depression on that side. (3) The stem settled into the soil below its original level, apparently under swaying wind action. When toppling, it appeared in some cases that the stem had been drawn downward and backward into the soil under tension of roots that did

not fail (Fig. 4). In these cases only a slight soil elevation occurred, in place of a root mound commonly associated with wind-thrown trees, and no depression caused by root displacement was noted. This type of toppling was found only on soils with moderately coarse textured profiles where a



FIG. 2.—Trees tilted but remaining upright in a plantation on Lakeland loamy sand (terrace phase). The root systems have been displaced from their original positions and serious damage to the trees has occurred.



FIG. 3.—A tree on Atlee very fine sandy loam that pivoted on nonfailing lateral roots when toppled in the direction of the wind. Note the depression beneath the stump (in which the axe handle extends) caused apparently by the root system being forced into the saturated soil.

restrictive layer existed.

General observations and notes were taken on the characteristics of tree root systems of toppled trees growing on soils with a restrictive layer in the lower profile. Figures 5A and 5B are views of an excavated root system of a large windthrown loblolly pine growing on Norfolk sandy loam, thick surface phase. The d.b.h. of this tree was about 20 inches. The root system is made up of a number of large main vertical roots extending to an approximate depth of 48 inches. At this depth, at contact with the restrictive layer in the profile, the main roots had given way to a series of smaller ramifying horizontal roots that had fused together into a broad, flat, woody surface. A few thickened

stubby roots penetrated beyond this level into the restrictive layer. Figure 5B shows the root system lying on its side and exposing the broad, flat, woody surface at the 48-inch depth. The observations are generally in agreement with other studies indicating the influence of such soil characteristics as restrictive layers on the growth of tree roots.

The results of this study agree with recorded information on hurricane damage. For Hurricane Hazel in 1954, there was little rainfall east of the storm's eye. Here, tree damage involved mostly broken or bent trees (8). Areas west of the eye received torrential rains, and uprooting of trees was common. In the present study of Hurricane Donna, damage was assessed

only in areas west of the storm's eye. Tree damage from Donna was mostly uprooting or severe root injury. Little damage was recorded for stem damage to trees that remained standing. Curtis (2) discussed the New England Hurricane of 1938 and stressed the tree damage resulting from heavy rains that preceded the storm.

Nelson and Stanley (5) related the degree of tree damage to thinning in East Texas following Hurricane Audrey in 1957. They found much more severe damage in heavily thinned slash pine plantations where residual stocking was low than in lightly thinned plantations where residual stocking was higher. Statistical tests of our data were inconclusive with respect to tree damage related to residual stock-

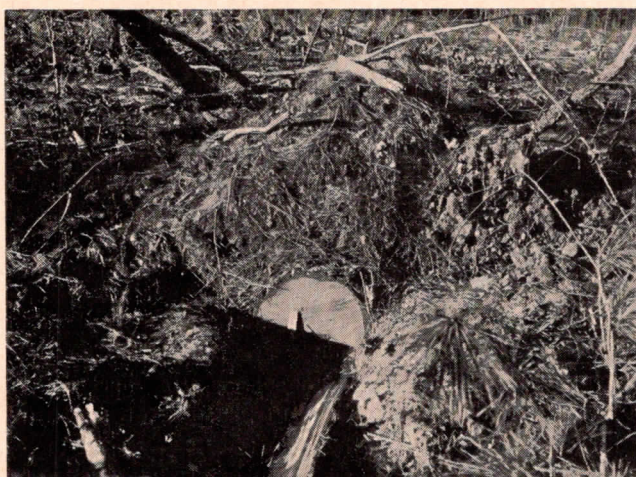


FIG. 4.—Some trees seemed to have settled into the soil under the swaying action of the wind before toppling. This type of wind-fall was noted only on soils with moderately coarse textured profiles with deep-lying restrictive layers. This soil was a nontypical Norfolk loamy sand. (L) The butt log of this tree was salvaged by winching it from the soil depression before cutting. The depression at the 3-foot stump height is about 1 foot deep. (R) The first 12-foot log of this tree was left embedded in the soil where it fell. Axe is over the stump.

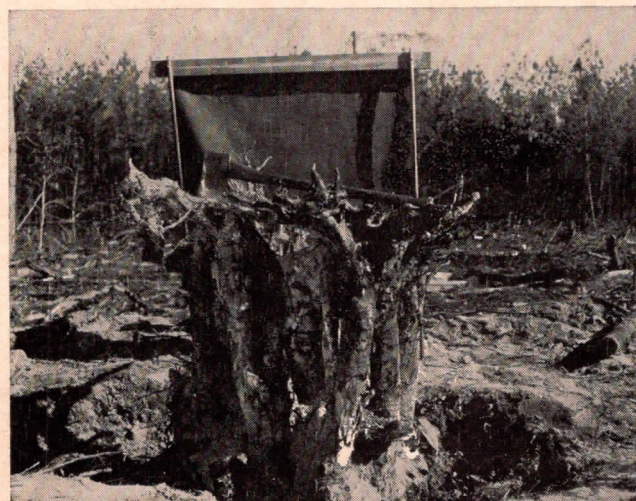


FIG. 5.—(L) Excavated and inverted stump of a loblolly pine. (R) View of same stump lying on its side. Note the absence of normal root development. At a soil depth of 48 inches a restrictive layer of impervious material was found. The root system was flattened and grew into a broad continuous woody surface just above the restrictive layer. The soil was a nontypical Norfolk sandy loam, thick surface phase.

ing of thinned stands.

Crocker (1) observed longleaf pine in Alabama following Hurricane Flossy. In a zone receiving 9 inches of rainfall during the storm, he found 90 percent of the blown-down trees were on soils underlain by clay or sandy clay at a depth of 24 inches or less. He assumed that restricted root development, along with soil saturation above the less permeable clay layer, was responsible for the severe blowdown. Our results appear to corroborate his findings.

Tree damage in this study appeared to result from a combination of high wind, excessive soil moisture and failure of the soil to provide adequate support. The strength of a soil in giving adequate tree anchorage and support comes from adhesive, cohesive, and friction properties of the soil. These properties are determined by size, shape, and arrangement of the soil particles and by the nature of the water films surrounding them. Silt and clay soils lose their cohesion and become plastic in the presence of increasing amounts of water. At a very high moisture content, the soil loses its plastic properties and approaches a fluid in its mechanical properties (9). The soil then has little or no shearing strength and is readily deformed. The relatively low degree of damage found on the silt and clay soils of this study (especially in the absence of fragipan-like restrictive layers that prevented adequate root and water penetration) suggests that these soils were able to retain a high degree of cohesion.

Sandy soils derive their strength for tree anchorage principally from shear resistance due to internal friction. This internal friction is proportional to the compressive forces between adjacent soil particles. The compressive forces are due to the weight of the soil. Under intense vibration of a water-saturated loose sand, part of this compressive force is transferred to the water, which has essentially no shear strength, and the result is a marked weakening of the soil to resist shearing (3).

Because of the higher permeability rates, the sandy or moderately coarse textured profiles of this study became saturated more rap-

idly than finer textured profiles. When restrictive layers were present, they created "perched" water tables. Excess water within the root zone, especially on soils with the restrictive layers, reduced the shear strength of these moderately coarse textured soil profiles. We believe this reduction in shear strength, together with inadequate depths of rooting in soils with a restrictive layer, accounts for some of the severe blowdown during Hurricane Donna.

With variation in wind speed, a tree bends and sways, and the tip is reported by Mergen (4) to oscillate in an elliptical pattern. This action places stress alternately on different sides of both the stem and the root system. Where soils lose their shear strength because of moisture, the tree root system may act as a giant stirring agent as a tree sways in the wind before it falls. This may explain the type of windfall illustrated in Figure 4 that was noted on moderately coarse textured profiles with restrictive layers. Here the weight of the tree seems to have forced the root systems deeper into the soil before toppling occurred.

There are some immediate practical uses for these findings. For instance, where timber stands are to be chosen or established for special research, high-value or long-time purposes, soil areas that predispose them to hurricane damage can be avoided. Such attention would apply to choosing seed production areas, establishing seed orchards, or outplanting rare and highly valuable trees. Planners of such activities should be particularly alerted to the hurricane hazards in this area on soils with moderately coarse textured profiles and on soils where a restrictive layer prevents adequate root and water penetration. Soil maps are helpful in this respect and the on-site assistance of a soil scientist may be an added insurance worthy of consideration.

Summary

Damage to recently thinned loblolly pine stands by Hurricane Donna was studied in an eight-county area of the coastal plain of Virginia and North Carolina. The area extended about 60 miles

northwesterly from the path of the storm's eye. This area received torrential rains preceding and during the storm.

Damage was assessed by determining the percentage of trees injured by the storm. Stand and soil characteristics were determined and recorded for sampled areas. Tree damage was recorded separately for "main stem" (breakage) and for "root system" (displacement from original position or blowdown). Over 99 percent of damaged trees were of the second type. Stem breakage was insignificant.

Damage was more severe on soils having moderately coarse textured profiles than on soils with finer textured profiles. It was most severe on nontypical soils of the series studied in which a restrictive layer occurred within the profile that tended to retard the taproot and water penetration. It is suggested that root systems fail to give adequate support to healthy loblolly pine trees during hurricanes because of reduced soil shearing strength when soils are excessively wet. It is also suggested that seed production areas, seed orchards, and other particularly valuable plots should not be established on such areas.

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