Some Factors of Climate and Soil Affecting Establishment of Loblolly Pine Stands

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Abstract. In the coastal plain of North Carolina, data collected over 10 years from burned, disked, or untreated logged tracts showed that the number of 1-year-old seedlings from natural seeding of *Pinus taeda* L. was directly related to the seed available and inversely related to April-through-June rainfall. With a given amount of seed, more seedlings were established on mineral soil than on burned seedbeds, and more on heavy-textured than on light-textured soils. Milacre stocking of free-to-grow seedlings three years after treatment depended on total milacre stocking in the first year, was reduced in proportion to basal area of residual hardwoods larger than 4.5 inches dbh, and was greater on heavy-textured than on light-textured soils.

REGENERATION of loblolly pine (*Pinus taeda* L.) in the South Atlantic Coastal Plain has been studied intensively since World War II and sufficient information has been published to answer many of the pressing questions in this field. Most of these studies have been reported separately and summarized by Wenger and Trousdell (1958).

The task of the forest manager who depends on natural regeneration would be lightened if he could predict the stocking of free-to-grow loblolly pine seedlings from a given amount of seed and various environments. It is the purpose of the present paper to give a separate and quantitative evaluation of important factors that influenced establishment and early growth of loblolly pine in a large study spanning a period of 10 years. Available data permitted separate evaluation of the factors affecting seedling establishment and those affecting early stand development, resulting in a better understanding of the regeneration process.

This new information shows that the abundance and early development of regeneration under forest conditions is not entirely governed by seed, site preparation, and competition control but is affected to a varying degree by weather conditions, the time since harvest cutting, and the forest soil.

Methods of Study

The regeneration studies were conducted in the Bigwoods Experimental Forest.[1] The experimental forest consists of 1,365 acres which bore, at the time of its establishment in 1945, an unusually uniform stand of mature or over-mature loblolly

[1]Maintained in Hertford County, N. C., by the U. S. Forest Service in cooperation with the Union Bag-Camp Paper Corporation, Franklin Division, Franklin, Va.

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pine of both forest and oldfield origin. It was divided into 37 units, or compartments, averaging 37 acres in size, of which 22 were selected for the study of natural regeneration of even-aged stands. The regeneration methods consisted of seed-tree and seed-strip cuttings in combination with three methods of site preparation with and without control of residual hardwoods 4.5 inches dbh and larger. The three methods of site preparation were burning after logging, single disking before logging, or logging alone.

Cutting and site preparation began in the winter of 1946, and were continued during the 7 succeeding years. Each treatment was applied in at least 5 of the 7 years of the study, so that year-to-year weather differences were well sampled. Beginning in 1949, treatments were scheduled each year to avoid a bias due to season of application.

The amounts of seed falling upon the land were estimated by means of a set of nine ¼-milacre seed traps in each of 14 compartments. Seed trees or strips remained standing to cast fresh seed upon each area during the 3 years of regeneration. Seedfall from residual seed sources ranged from 4 thousand to 144 thousand sound seed per acre in the first year after harvest cutting.

Residual hardwoods 4.5 inches dbh and larger were inventoried after harvest cutting, site preparation, and hardwood control. Basal area of residual hardwoods ranged from 0 to 24 sq ft per acre.

Within each of the 22 compartments, 100 systematically located milacre plots were established prior to regeneration. Following logging and ground preparation, the seedbed condition of these plots was classified as (1) disturbed to mineral soil, (2) burned, (3) covered with slash, or (4) undisturbed. The soils on which each plot occurred were also recorded. Counts of seedlings of age 1, 2, and 3 years on these 2,200 plots furnish estimates of numbers and stocking of reproduction. At age 3 the stocking of pine seedlings free to grow was estimated.

TABLE 1. Characteristics of the major soil groups in the Bigwoods Experimental Forest.

Soil series and type	Subsoil texture
HEAVY TEXTURED	
Poorly drained	
Bayboro loam[1]	Clay
Bladen silt loam	Clay
Coxville silt loam	Clay
Moderately well drained	
Lenoir silt loam	Silty clay
Craven v.f.s. loam	Fine sandy clay
Lynchburg v.f.s. loam[1]	Very fine sandy loam
Dunbar f.s. loam[1]	Fine sandy clay loam
Shubuta v.f.s. loam[1]	Fine sandy clay
LIGHT TEXTURED	
Well drained	
Myatt sandy loam[1]	Sandy clay loam
Stough f.s. loam[1]	Fine sandy loam
Cahaba sandy loam	Sandy clay loam
Kalmia-huckabee f.s. loam	Loamy fine sand
Huckabee fine sand	Loamy fine sand

[1]These soils occupy only small areas in the experimental forest.

The soils of the experimental forest fall into three distinct groups: (1) poorly drained silt loams with very plastic clay subsoils, (2) moderately well-drained silty clays to sandy clay loams with plastic clay subsoils, and (3) well-drained sands to sandy loams with fine sand to sandy clay loam subsoils (Table 1). Each group occurs within a fairly well-defined area of considerable size in the experimental forest. The heavy-textured soil groups are upland soils formed from marine sediments. The sandy or light-textured soil group is made up of alluvial soils occupying old, high stream terraces no longer subject to flooding. In the aggregate the soils of the experimental forest are representative of a substantial portion of the South Atlantic Coastal Plain (Wenger and Trousdell 1958).

Rainfall averages 48 inches annually and is heaviest in the summer months, lightest in the fall, and intermediate in the winter and spring. The amounts of monthly rainfall for the period of the study were obtained from U. S. Weather Bureau summaries for the weather station at Holland, Va., about 20 miles from the experimental forest. The rainfall record at Holland spans 24 years and during the 7-year period of this study the highest and second lowest spring rainfall occurred, 16.1 and 7.8 inches, respectively.

Results

Seedling establishment. The basic data for the study of the factors affecting the initial establishment of seedlings were individual milacre counts of seedlings and the associated observations of seed supply, initial seedbed conditions, soil groups, and rainfall.

Because logging slash and undisturbed litter tend to prevent contact of pine seed with mineral soil, it seemed likely that the effects of soil characteristics and rainfall would be masked by these two seedbed conditions. Therefore, plots in logging slash and undisturbed litter were not included in the analyses of seedling establishment, leaving 1,607 plots with disturbed or burned seedbeds. These plots were segregated according to year of establishment and the three soil groups. This procedure yielded 39 separate estimates of the number of seedlings established per acre which differed in year of establishment, seedbed condition, and soil group. The number of milacre plots supporting each estimate varied from 5 to 85. The number of seedlings per acre established in the first year ranged from 600 to 19,400.

To relate seedling establishment and rainfall, the period when rainfall is critical must be determined. Preliminary plotting of seed-seedling ratios indicated that the period March through June was critical. Various expressions of the rainfall occurring during this period were tested in regression analyses to determine their effect on seed-seedling ratios. These expressions of rainfall were inches of rainfall March through June, April through June, the reciprocal of April through June rainfall, the reciprocal of the value April through June minus 6, and the reciprocal of the value April through June rainfall minus 7. The rainfall expression accounting for the greatest proportion of the variation in the seed-seedling ratios was the reciprocal of the value April through June rainfall in inches minus 7.

This expression was then used as the rainfall variable in a multiple regression analysis to determine the relation of the number of seedlings established to seed supply, initial prepared seedbed conditions, soil groups, rainfall, and the first-order interactions among these variables. The relation of seedling establishment to the significant independent variables was as follows:

$$Y = 1.795 + 1.114(M) + 3.860(S) + 8.668(T) - 0.893\left(\frac{M}{R-7}\right)$$

in which

Y = hundreds of seedlings per acre
M = thousands of sound seed per acre
S = heavy-textured soils (+1), light-textured soils (−2)[2]
T = disturbed seedbed (+1), burned seedbed (−1)
$R-7$ = April-June rainfall minus 7.

The independent variables accounted for 74 percent of the observed variation in numbers of seedlings established per acre. The amount of seed and the seed-rainfall interaction together accounted for 51 percent of the variation. No other first-order interactions were significant.

The relation confirms earlier findings on the importance of seed supply: under any given combination of the observed conditions, the number of seedlings established was in direct proportion to the amount of sound seed supplied (Fig. 1) (Trousdell 1950).

On the average, nearly 1200 more seedlings per acre were established on the heavy-textured soils than on the light-textured soils with a given amount of seed. The superiority of a disturbed mineral soil surface

[2]Figures in parentheses show the values to be substituted in the equation to solve for the variables selected.

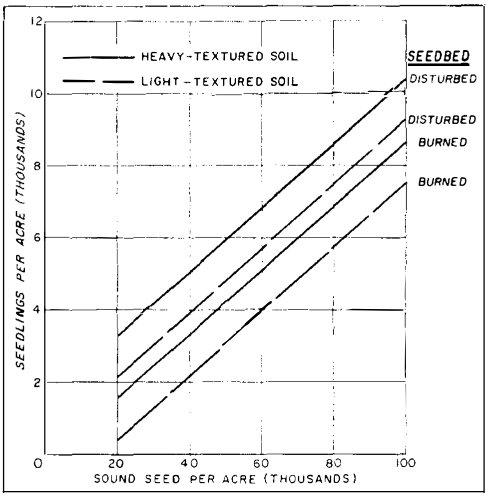

FIGURE 1. *Number of seedlings per acre established in the first year after logging or seedbed preparation in relation to seed supply, soil textural group, and seedbed condition, with average April-June rainfall.*

to a burned surface is also corroborated (Pomeroy 1949), with an average of 1700 more seedlings established on disturbed than on burned seedbeds with the same amount of seed.

The effect of rainfall on seedling establishment varied with the amount of seed available. With a comparatively small amount of seed, rainfall in amounts between 8 and 10 inches during the April-June period strongly influenced the number of seedlings established (Fig. 2). Seedling establishment was not greatly increased by more rain, even up to a total of 16 inches. With an ample amount of seed, the importance of rainfall up to 10 inches was prominent; the number of established seedlings increasing sharply with each additional inch of rain. The number of seedlings continued to improve substantially but by much smaller increments, with additional inches of rain above 10.

Seedling dominance. While the number of seedlings per acre lends itself to the analysis of factors affecting seedling establishment, a value much more useful to the forest manager is the stocking percentage, that is, the percentage of quadrats of specified size containing one or more established seedlings (Lynch and Schumacher 1941). This value reflects not only the number of seedlings per acre but also their distribution; it is, therefore, a more useful expression of the amount of effective reproduction in a tract than the number of seedlings per acre.

In the past, the success of regeneration could not be reliably judged until 3 years after logging or site preparation (Brender and Nelson 1954, Wenger 1955), because criteria for earlier evaluation of prospective dominance of seedlings had not been developed. However, the earlier the success of regeneration can be evaluated, the sooner remedial measures can be applied. The data collected in the present study permitted an analysis of the relation of third-year stocking to earlier stocking.

Since stocking percentages are unreliable when the number of quadrats is small, compartment averages based on 100-milacre

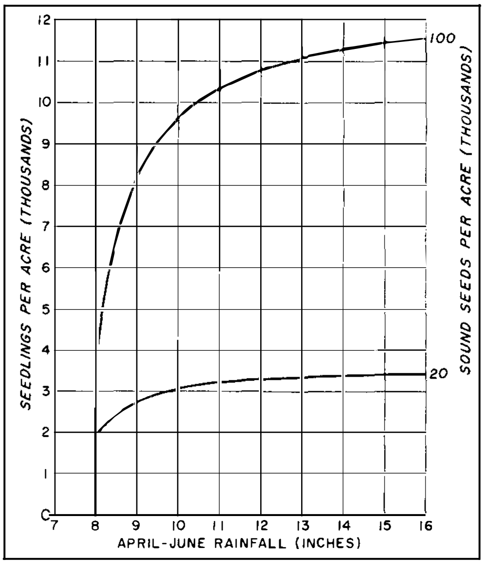

FIGURE 2. *Number of seedlings per acre established in the first year after logging or seedbed preparation on heavy-textured soil and disturbed seedbed in relation to rainfall and seed supply.*

plots were used for this analysis. Twenty-one compartment averages were available. Compartment averages of total first-year pine stocking ranged from 43 to 97 percent and free-to-grow stocking at 3 years from 30 to 91 percent.

Preliminary analyses were made using third-year free-to-grow stocking as the dependent variable, and site preparation, total first-year stocking, soil texture, and basal area of hardwoods over 4.5 inches dbh as independent variables. The site preparation treatments were not significant when total first-year stocking was included as an independent variable. First-year stocking is apparently a direct measure of site preparation effects.

The final analysis included, as independent variables, the total stocking percentages in the first, second, and third years after logging or site preparation, the basal area of residual large hardwoods, the two major soil textural groups and the first-order interactions among these variables.

Total first-year stocking, soils, and basal area of residual hardwoods made significant contributions to the variation in third-year stocking of free-to-grow seedlings. The relation derived from the data was as follows:

$$P_3 = 12.5334 + 0.83296\,(P_1) + 6.0778(S) - 0.01289\,(P_1B)$$

in which

P_3 = stocking of free-to-grow seedlings at 3 years

P_1 = total stocking at 1 year

S = heavy-textured soils (+1), light-textured soils (−1)[3]

B = basal area of residual hardwoods 4.5 inches dbh and larger, plus 1.

The significant variables accounted for 86 percent of the variation in third-year stocking of dominant seedlings. First-year total stocking alone accounted for 62 percent of the variation. Of the significant variables, total first-year stocking is, therefore, the major determinant of third-year stocking of dominant seedlings (Fig. 3).

Residual large hardwoods have a comparatively small effect on third-year stocking when first-year stocking is light, but an increasing effect with heavier initial stocking. For example, on the heavy-textured soils with 25 sq ft of basal area per acre in large residual hardwoods, 60 percent initial total stocking was reduced 12 percentage points to 48 percent free third-year stocking, while 90 percent initial stocking was reduced 27 percentage points to 63 percent of free third-year stocking.

A higher proportion of established seedlings became dominant on the heavy-textured soil group than on the light-textured soil group; for a given initial stocking and hardwood basal area, third-year free-to-grow stocking was 12 percentage points higher, on the average, on these soils. With no competition from residual hardwoods, free-to-grow stocking at 3 years on the heavy-textured soils actually tended to be higher than total initial stocking, especially where initial stocking was low. These increases result from seedlings that became established from second- and third-

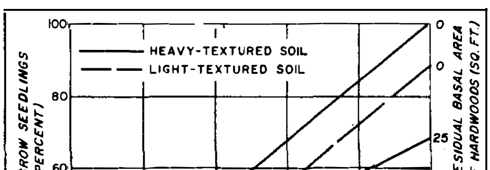

FIGURE 3. *Stocking of free-to-grow seedlings at 3 years in relation to total stocking at 1 year, soil textural group, and two levels of basal area of residual hardwoods.*

[3]Figures in parentheses show the values to be substituted in the equation to solve for the variable selected.

year seeding, and under favorable conditions became free-to-grow.

Discussion

Rainfall. The effect of rainfall on seedling establishment has not previously been quantitatively demonstrated, although amounts and timing have long been recognized as important. The pre-eminent effect of April-June rainfall on seedling establishment indicates that seedlings that survive these months withstand subsequent moisture fluctuations quite well. With other factors the same, the amount of reproduction is increased as periodic rainfall increases. At one extreme, increasing rain from 8 to 9 inches greatly increases the abundance of reproduction, while at the other extreme the improvement in reproduction is unimportant if periodic rainfall is increased as much as 4 inches or from 12 inches to 16 inches. The critical amount of rainfall, during the important April-June period, appears to be about 10 inches. With 10 inches or more of rain, seedling establishment depends on the amount of seed, seedbed preparation, and soil factors. With less than 10 inches of rain, reproduction is less abundant and large amounts of seed or more severe site preparation are needed to compensate for moisture deficiencies.

Rainfall apparently is usually adequate for pine seedling establishment in the locality of the study. The 24-year rainfall record 1933 to 1957, available from the Holland, Va., weather station shows an average April-June rainfall of 11.34 inches, while the average for the 7 years of the seedling establishment phase of the study was 11.41 inches. The study period included the highest April-June rainfall, 16.1 inches, and the second lowest, 7.8 inches, of the 24-year period. For Tidewater Virginia as a whole the long-term average April-June rainfall is 10.4 inches; for the north, central, and south coastal plain of North Carolina the corresponding averages are 10.9, 11.5, and 11.0, respectively. Thus rainfall variations during the study period were representative of long-term variation as well as of a large geographic region.

Regeneration may fail occasionally because of insufficient rain, particularly on light-textured soils when the seed supply is small.

Soils. As with rainfall, the effect of soil physical characteristics on establishment of loblolly pine seedlings has not heretofore been shown, although it has been suspected. The variability of the Bigwoods soils is reflected in the textures of both surface and subsoils, which tend to be correlated even though surface soils are mainly in the loam class (Table 1). Consequently, the observed differences in seedling establishment occurred probably because both surface and subsoils affected germination and early survival similarly. Unfortunately, the data did not permit separate analyses of germination and early survival because seedlings were counted only at the end of the growing season.

With the wide range in soil textures and variable moisture supplies, a rainfall-soil texture interaction would logically be expected. That this interaction was not significant suggests that rainfall varied within too narrow a range, in general, to overcome during any period the effects of soil texture or moisture availability. If rainfall during an appreciable period of the study had been so low that no seedlings were established on any soils, or so high that similar numbers were established on all soils, the interaction would probably have been significant.

Although the relation of seedling establishment to seed supply, soils, seedbed condition, and rainfall was derived from data on natural seeding, it should also be helpful in planning direct seeding under similar conditions. While seed requirements may be appreciably reduced, the effects of soils, seedbed conditions, and rainfall are not likely to be altered by the bird and rodent repellents used in treating seed for direct seeding.

Time since harvest cutting. Third-year stocking of free-to-grow seedlings was significantly related to total first-year stocking but not to total stocking in the second or third year. This result substantiates the conclusion drawn earlier from portions of these data that natural regeneration of loblolly pine occurs in the first year after harvesting cutting (Wenger and Trousdell 1958). Thus, with proper planning no more time is required to regenerate stands by natural seeding than by planting or direct seeding, in the South Atlantic Coastal Plain. The one year in the nursery bed gives planted seedlings comparatively little advantage under forest conditions in that locality (Gruschow 1959).

For any level of initial stocking, third-year free-to-grow stocking was greater on the heavy-textured than on the light-textured soils. Hardwood sprouts and seedlings grew more slowly and loblolly pine seedlings grew faster on the heavy soils than on the light-textured soils (Wenger 1955, 1956), so that seedlings on the heavy-textured soils were subjected to less competition, and a greater proportion of them reached free-to-grow status.

Third-year free-to-grow stocking was greater than initial stocking on heavy-textured soils when hardwood competition was absent. Apparently, the conditions that permit a higher proportion of first-year seedlings to become dominant also permit establishment of additional seedlings in the second and third year. These increases are comparatively small, however, and in themselves would not result in satisfactory stocking of free-to-grow seedlings.

The effect of large hardwoods on pine regeneration is related both to the abundance of hardwoods and the stocking of pine seedlings (Fig. 3). Since stocking percentages reflect not only the number of seedlings present but also their distribution, a greater proportion apparently occur under hardwoods when stocking is high.

The high precision of the relation of third-year free-to-grow stocking to initial stocking, soils, and residual hardwoods will permit its use to evaluate the success of regeneration 1 year after natural or direct seeding on soils similar to those in the study area. It will also provide an estimate of the benefit to be gained by eliminating large, overtopping hardwoods.

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