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SILVICULTURE OF LONGLEAF PINE

(Second of a Series on the Silviculture of Southern Forests)

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Sponsored by the Conservation Foundation

(A preface to this series is given in the first issued, *Silviculture of Shortleaf Pine*, S.F.A. Bul. No. 9.)

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SCHOOL OF FORESTRY

NACOGDOCHES, TEXAS

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SILVICULTURE OF LONGLEAF PINE

Longleaf pine[1-2] prevails along the Gulf Coast from Louisiana to west Florida, though it occurs throughout most of the balance of the Coastal Plain. Pure stands probably once occupied half of the southern pine area. Longleaf pine grows on clay as well as sand regardless of fertility, the principal demand upon the site being for adequate soil moisture which is particularly limiting to growth when vegetative competition is severe. Yet this is typically a dry-site species, xero-mesic oak-hickory stands replacing it in soils with high water-holding capacity in clay layers. Longleaf pine is not found on wet sites except when droughts accompany abundant seed fall and fires that eliminated shrub shade. Hence, soil moisture and fire history are responsible for the occurrence of the several types: pure longleaf, longleaf pine-slash pine, and longleaf pine-turkey oak (Soc. Amer. For., 1954). Loblolly and shortleaf pines mix with longleaf pine in loamy flatwoods, while southern red oak and sweetgum occur on drier sites (Fig. 1).

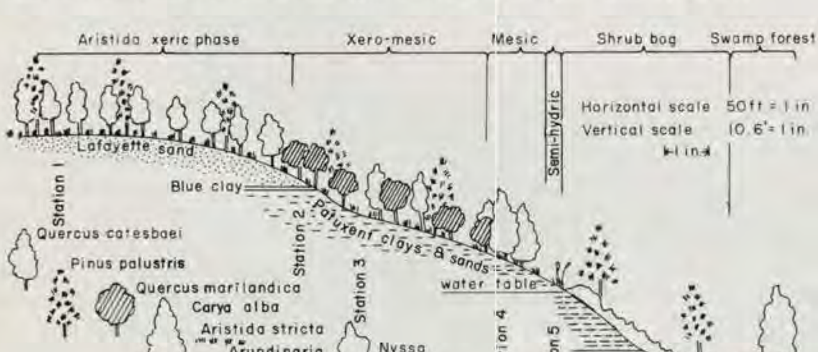

Figure 1—Drawing of a transect from hill-top to swamp. Longleaf pine is everywhere except in the swamp (Wells and Shunk, 1931).

Longleaf pine is more shade-tolerant than slash pine (Mattoon, 1916), but less so than other southern pines. A fire-subclimax type, this species dominates the forest only as long as periodic fires occur. In pre-historic times, dead snags struck by lightning burned, setting grassy longleaf pine forests on fire. With fire exclusion, the natural range has been receding, giving way to slash pine along the eastern Gulf and Atlantic coasts, and to loblolly pine in the western part of the Gulf coastal area. Acreage decline is also due to (1) overcutting which left vast expanses without even a single seed tree, (2) hog grazing on seedlings rich in carbohydrates, and (3) brown-spot needle blight which effectively keeps seedlings in the grass stage for up to 25 years. Further decline is expected as fire protection improves and because slash pine plantations are easily established. How-

[1]Wahlenberg's (1946) monograph, *Longleaf Pine*, is called to the reader's attention, and Muntz (1954) authored a Farmers' Bulletin on this species. Silvical characteristics are reviewed in Agr. Handbook No. 271 (USFS, 1965).

[2]Scientific names of species mentioned are given in the *Appendix*.

ever, replacement species may not endure the drier longleaf pine sites, and the rot caused by *Fomes annosus* in slash pine plantations may retard type conversion.

The longleaf pine-slash pine type is predominant in the sandy flatwoods where hardpans underlie the surface soils. Here, it is subject to conversion to pure stands of either species as the occurrence together of longleaf and slash pines is difficult to manipulate artificially. Both, as do all southern pines, require a mineral seed bed for seed germination. Sand pine and saw-palmetto are also local associates, the latter serving as a nurse plant to longleaf pine seedlings by protecting them from lethal temperatures and the soil from desiccation. In a southern Mississippi stand, 90 percent of the longleaf pine seedlings occurred within 2 feet of saw-palmetto clumps, even in openings 25 feet across (Allen, 1956). In the slash-longleaf flatwoods, saw-palmetto dominates most understories, gradually being replaced by gallberry on the moister sites, and by wiregrass on the drier sites (Wilhite and Ripley, 1965).

Gopher-apple is an indicator of dry locales, while waxmyrtle and gallberry are indicative of moist sites. Wiregrass is an indicator of medium to coarse sandy sites in the absence of other vegetation in uplands and where lower slopes transition to semi-hydric bogs. Its tuberous roots, with extensive laterals in the upper 4 inches of soil, serve as water reservoirs when surface soils are dry. They descend to depths of more than a foot when water tables are below a few feet of the surface. The wiregrass range, in terms of soil moisture levels, is about the same as for longleaf pine, although it is rarely found in old-fields in the Atlantic Coastal Plain (Wells and Shunk, 1931). Other pioneer plants in longleaf pine-turkey oak sites include lichens, but competition may be so great that even these are inhibited. Longleaf pine in inland areas cannot survive even in the shade of sweetfern brush if the water table is below the reach of seedling roots.

In East Texas, virgin longleaf pine occurred on poor dry, flatlands of gray, sandy surface soil underlain by pale, yellowish, or mottled clay loam. In contrast, shortleaf pine-loblolly pine stands were found on the red soils of the rolling "red hills." Longleaf pine was then, as now, absent in the dark, moist, loamy soils of lower elevations where loblolly pine is mixed with hardwoods. Virgin longleaf pine stands in Louisiana, however, occurred on hard, dry, clay soils as well as on the sand ridges. Humus was not present in these longleaf pine forests, probably due to frequent burning (Ness, 1927; Larsen, 1910).

Dry Sites

In the sandy, dry, well-drained upland soils of the lower Coastal Plain, where vegetation burns easily because of its low water content, turkey oak replaces longleaf pine upon elimination of fire. Eventually the stands are pure scrub oak and include bluejack, blackjack, and post oaks.

Large seed helps longleaf pine become established as a pioneer species on dry sites because carbohydrate food, stored for early use by the penetrating tap root, is available to enable growth to horizons of available water during drought in sandy soils of low capillarity. The high carbon-nitrogen ratio, low total nitrogen, and very low carbon dioxide evolution are indicative of the infertility of these coarse-textured soils which are too poor for any but the most xeric and least nutrient demanding species.

Growth

Best growth of longleaf pine seedlings occurs when soil moisture is maintained between 25 and 35 percent, as optimum transpiration, needle growth, dry weight gain, and root growth then takes place. Very wet and very dry periods are endured even during the first year (Pessin, 1938).

Measurements on 7 trees in South Carolina indicated diameter growth was initiated on February 10 and ceased September 30 to November 11 (Harkin, 1962). Allen (1964) calculated that 6-year-old saplings made 31 percent of their spring elongation from food reserves in the woody stem and 15 percent from that in the roots; old needles apparently furnished materials for 40 percent of the elongation.

Size, Volume, and Stocking

Old-Growth

At 150 years,[1] trees of virgin stands frequently exceeded 6-log lengths and averaged 20 inches dbh. Volumes amounted to 100 cubic feet per tree (Wahlenberg, 1946). On poor sites, such as deep sands, virgin forests yielded as little as 2 to 3 MBM per acre in contrast to 20 to 30 MBM on moist well-drained sites. Yields in pure evenaged virgin stands as determined by Chapman (1909) for various ages were: 100 years, 9 MBM; 200 years, 15 MBM; and 300 years, 14 MBM per acre. A decreasing yield with age beyond 250 years for these stands was probably due to reduction in stand density as overmature stems died. Stocking of 60 trees per acre at age 100 was reduced to only 10 trees—considered a full stand—at age 300. Dbh growth of old 10-inch trees was 2 to 3 inches for a 20-year period, but was reduced to 1.4 inches for stems in the 28-inch class. Over a 20-year period, volume growth for large trees (20 inches dbh) is as much as 150 board feet (Doyle), but growth during this period amounted to only 13 percent of the total volume. In contrast, for 12-inch trees, increment was 87 percent (65 board feet) of total volume over the 20-year period.

Second-Growth

The rotation age is dependent, principally, upon product desired. Pulpwood harvests may be at age 35, and sawtimber rotations at 70 years, although Mattoon (1916) predicted 50 years as a probable maximum rotation for longleaf pine under management. Stands established at the time of that prediction on certain sites have substantiated the prophecy. Trees may be large enough for sawlogs in 25 years. By age 40, yields range from 2 to 12 MBM per acre, and may exceed 22 MBM over a 70-year rotation. Well-stocked stands contain about 750 stems per acre at age 15, and between 300 and 400 in 30 years. Second-growth managed forests grow considerably faster, but structural quality may not be equivalent to old-

[1]Add 5 years to ring counts in determining ages of longleaf pine stumps; add 8 years to increment core counts at breast height.

growth. Well-stocked second-growth longleaf pine stands approach in 70 years the volume that virgin stands produced in 2 centuries.

At age 42, a stand in south Mississippi produced 44 cords of wood per acre, including 12 MBM of sawtimber (Table 1, Fig. 2). The soil of the area is deep well-drained fine sandy loam with SI 80. Another stand

TABLE 1. A LONGLEAF PINE STAND FROM AGES 13 THROUGH 42; DATA FOR TREES LARGER THAN 3.5 INCHES DBH (after Smith, 1955a).

Age	Trees	Average dbh	Basal area	Mean annual basal area growth	Volume	Mean annual volume growth	Periodic annual net vol. gr.
	No.	Inches	Sq. ft.	Sq. ft.	Cords	Cords	Cords
13	133	4.2	13.1	1.0	1.2	0.09	—
18	251	4.9	33.3	1.8	4.4	.24	0.64
23	346	5.7	61.0	2.6	11.7	.51	1.46
28	386	6.3	83.5	3.0	20.7	.74	1.80
37	383	7.4	115.6	3.1	38.6	1.04	1.99
42	347	8.8	117.0	2.8	43.8	1.04	1.04

of 400 trees per acre grew 2 cords per acre per year between ages 25 and 35. Total yield at 35 years was 40 cords per acre or 8 MBM in trees 9 inches dbh and larger. Growth expected in the second 35 years is 400 board feet per acre per year (Smith, 1950, 1950a, 1953, 1955a).

Figure 2—Growth per acre in this longleaf pine stand averaged 44 cords in 42 years (Smith, 1955a; USFS photo).

Understocked stands in the Coastal Plain of Georgia, under management only 5 years, grew at the rate of 27 percent annually in board foot volume. Had the stands been fully stocked, growth is estimated at more than 400 board feet per acre per year (Hawley, 1952). Annual growth in stands in south Alabama just coming under management, approaching 250 board feet and 0.6 cord per acre, should double after the stands are managed for several decades (Croker, 1960).

A 40-year-old plantation, established from seed at a spacing of 10 x 10 feet "when children ate longleaf pine seed on their way to school," produced 18 MBM or 44 cords per acre. Growth decreased after age 30 because of overstocking (Ross, 1942). Even trees appearing stagnated may make exceptional growth when released, as evidenced by an overstocked 130-year-old virgin stand which averaged 9 inches dbh, but which grew to 42 inches average dbh in the 130 years following release (Chapman, 1941).

Species Comparisons

Growth and yield of longleaf pine on moist sites is generally less than for loblolly or shortleaf pines. On the other hand, longleaf pine is better acclimated and produces more wood on dry sites. In the early years—up to perhaps age 30—longleaf pine is out-grown by slash pine due to the many years the former may remain in the grass stage. However, longleaf pine often surpasses slash pine at about age 30, neither tip moth or webworm impeding its growth. Loblolly pine coming in under young longleaf pine sapling stands has overtaken the latter, though this is not common (Ross, 1942). But while longleaf pine requires prescribed burning for brown-spot control among grass-stage seedlings, slash pine seedlings are readily killed even by cool fires. It is only rarely, then, that the two species pass the seedling stage together. Slash pine begins making height growth the first year, while longleaf pine often delays 10 years—but with proper silvicultural practices initiates height growth in the third to fifth growing season. After height growth begins, fire must be excluded, for longleaf pine seedlings less than 10 feet tall are susceptible to fire injury, although many over 2 feet tall endure some fire under favorable weather and fuel conditions.

Before age 10, slash pine may be over 15 feet tall and rather resistant to fire injury. This silvical inconsistency for these species accounts for their exclusiveness in managed stands. They are found together in nature probably because fires either occurred or did not occur at the opportune time, or because slash pine seeded in before longleaf pine seedlings began height growth but following a fire which exposed mineral soil.

A state-wide survey in Alabama showed no significant difference in annual diameter growth of longleaf and slash pines. However, longleaf grew significantly better than shortleaf and poorer than loblolly pines (Judson, 1965).

Nanism

Temporary nanism, or dwarfing, of longleaf pines in the grass-stage is often attributed to vegetative competition. However, after a very exhaustive study, Brown (1964a) concluded that the grass-stage condition is an inherent seedling trait under rigid genetic control, although the length of time individual seedlings remain in the grass-stage is strongly influenced by the environment. The short-shoot habit may be associated with auxin production in the buds during early stages of development (Brown, 1958); the inhibition of active height growth is positively correlated with the inhibition of polar auxin transport (Brown, 1964a). Wahlenberg (1934) noted that most severely stunted seedlings have (1) conical stems, the sharp taper indicating weak terminal growth caused, perhaps, by severe suppression, or (2) adventitious swelling and gnarled tops due to repeated injury from brown spot needle blight and fire. Flat buds formed due to the latter condition produce only a cluster of foliage. In contrast, vigorous seedlings are cylindrical and with white, sharp-pointed buds.

The popular belief that seedlings remain in the grass-stage until tap roots reach moist zones is unfounded. Three months after germination, tap roots were 4 to 7 inches deep, and as many as 25 laterals up to 3 inches long had developed. After 5 months, tap roots were more than 10 inches deep and laterals numbered 60.

Stands of seedlings have remained in the grass-stage for 25 years, and 15 years is not unusual (Ware and Stahelin, 1948). Generally, dominance is expressed early enough for an adequate stand to reach breast height in about 8 years, in which case height growth begins at about 5 to 6 years of age (Chapman, 1948). Controlling competition and brown spot needle blight may reduce this by several years, for seedlings stay in the grass-stage until they reach 1 inch in diameter at the root collar and, almost invariably, begin height growth upon attaining that size (Table 2).

TABLE 2. AVERAGE ROOT-COLLAR DIAMETERS OF RELEASED AND UNRELEASED SEEDLINGS AT FOUR YEARS (from Walker, 1954).

Time of release	Escambia		Conecuh	All
	Poor site	Good site	Good site	sites
		Inch		
At age 1	0.48	0.46	0.62	0.53
At age 2	.39	.39	.58	.46
At age 3	.32	.32	.46	.37
Unreleased	.25	.34	.41	.34

Changes in the terminal bud during the grass-stage have been described by Pessin (1939):

1. the fascicular meristem lies in a horizontal plane forming a flat surface out of which the fascicles arise.
2. a slight convex curvature develops in this fascicle-bearing surface, and a semblance of bud appears.
3. a typical silvery-white pointed bud is formed which develops into the main axis, and from which lateral fascicles arise.
4. after the conical bud appears, elongation of the main axis is rapid and dominance is strongly expressed, more so than for any other southern pine.

Site Index

Site indexes in the Coastal Plain uplands are generally lower for longleaf pine than for shortleaf, loblolly, and slash pines, the difference amounting to 9 to 15 units in the middle Coastal Plain (Bennett, 1953). Longleaf pine site indexes are between 70 and 80 for soils well-suited for row crops, but reach 120. Cruikshank (1954) found SI 57 average for North Carolina, 60 for South Carolina, 66 for Georgia, and 59 for Florida. In Georgia, site index in the Piedmont is 4 points lower than for the Coastal Plain (Fig. 3).

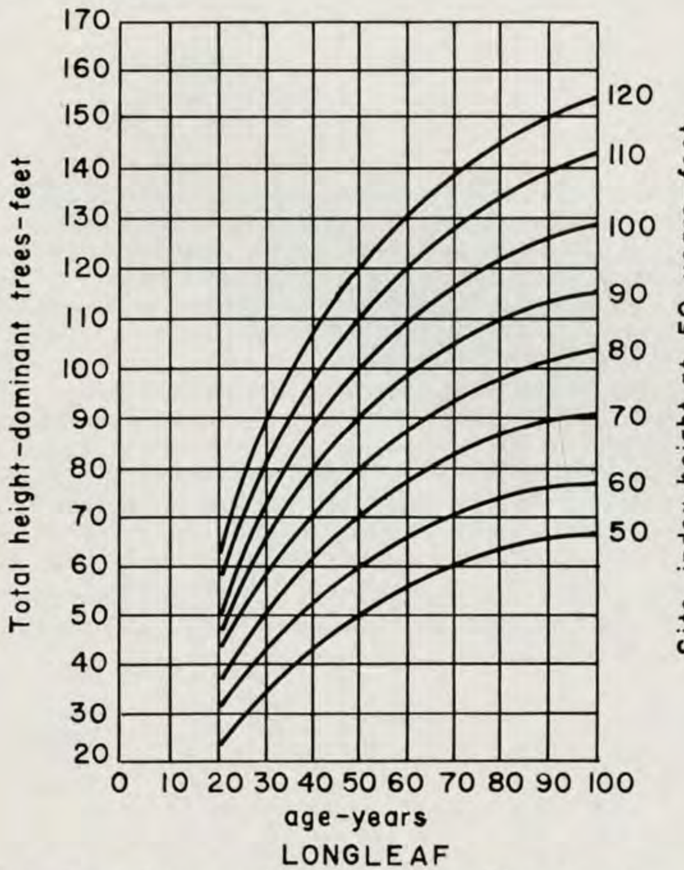

Figure 3—Site index curves for longleaf pine (from Anonymous, 1929).

Site Index Estimation

Assuming that soil and climate are related to the growth of longleaf pine, McClurkin (1953) determined a regression for the western portion of the species' range:

$$\text{Log SI} = 1.8697 + 0.0002636\ (R)\ \ (D) - 0.006734\ (D)$$

where R = average rainfall in inches for January through June, and D = the depth in inches to the least permeable soil horizon.

The least permeable horizon may be a hardpan or simply a silty layer underlying a loamy surface soil (Table 3).

TABLE 3. SITE INDEX OF LONGLEAF PINE (INTERPOLATE INTERMEDIATE RAINFALL AND DEPTHS) (after McClurkin, 1953).

Depth to least permeable horizon (inches)	Rainfall, January through June		
	24 - 26 inches	28 - 30 inches	32 - 34 inches
	Site Index		
0-5	74	74	75
11-15	73	76	78
21-25	73	77	82
31-35	72	79	85

At variance with this is the assertion that the influence of precipitation upon the width of annual rings of longleaf pine in Florida depends upon the amount of precipitation each month, but not its distribution throughout the year. Schumacher and Day (1939) noted that an increase of 0.5 percent in annual ring width occurred with each inch increase in monthly precipitation. However, only 3 to 12 percent of the variation in annual ring width for a number of species was ascribable to climate.

Along the Atlantic Coastal Plain, from North Carolina to northern Florida, Ralston (1951) and Coile (1952) found subsoil the principal productivity factor, site index increasing as subsoil texture becomes finer. Theoretically, moisture equivalent,[1] rather than texture, is the criterion involved, but the direct relation of moisture and texture and the convenience of textural classification make estimation on the basis of texture practical (Table 4). Moisture equivalent is important because subsoils

TABLE 4. MOISTURE EQUIVALENT VALUES ACCORDING TO TEXTURAL GRADE OF SUBSOIL (after Ralston, 1951).

Subsoil textural grade	Moisture equivalent range	
	Well-drained sites	Poorly- and imperfectly-drained sites
	Percent	Percent
Sand	2 - 3½	2½ - 4½
Loamy sand	6 - 7½	6 - 8
Sandy loam	11 - 17	10 - 14½
Sandy clay loam and sandy clay	18 - 20½	17½ - 20
Finer than sandy clay	22½ - 26	22 - 26½

furnishing large amounts of available water are associated with soils having a greater silt + clay fraction and better site quality.

[1]Moisture equivalent is the amount of water retained in the soil after centrifuging at 1000 times gravity. The value approximates field capacity—the percent of the soil weight that is water 24 hours after a soaking rain. Moisture equivalent values have been worked out for a number of soil series based on texture classes, the averages of which for all drainage conditions are listed in Table 4.

On the more poorly drained soils, site index increases with depth to mottling, indicating growth is better where soils are more favorably drained. As depth to mottling is indicative of the amount of growing space roots have above poorly aerated strata, favorable responses to artificial drainage are expected on poorly drained and imperfectly drained sites (Tables 5 and 6).

TABLE 5. SITE INDEX OF LONGLEAF PINE ON WELL-DRAINED SOILS IN THE SOUTHEASTERN COASTAL PLAINS AS INFLUENCED BY THE TEXTURE OF THE SUBSOIL (from Coile, 1952).

Subsoil characteristics		Site Index	
Texture	Moisture equivalent (percent, wt. basis)	Well-stocked stands	Poorly-stocked stands
Sands	3	64	58
Loamy sands	7	65	59
Sandy loams	13	66	60
Sandy clay loams	19	68	61
Sandy clays	25	72	62
Light clays	30	76	63
Heavy clays	35	77	64

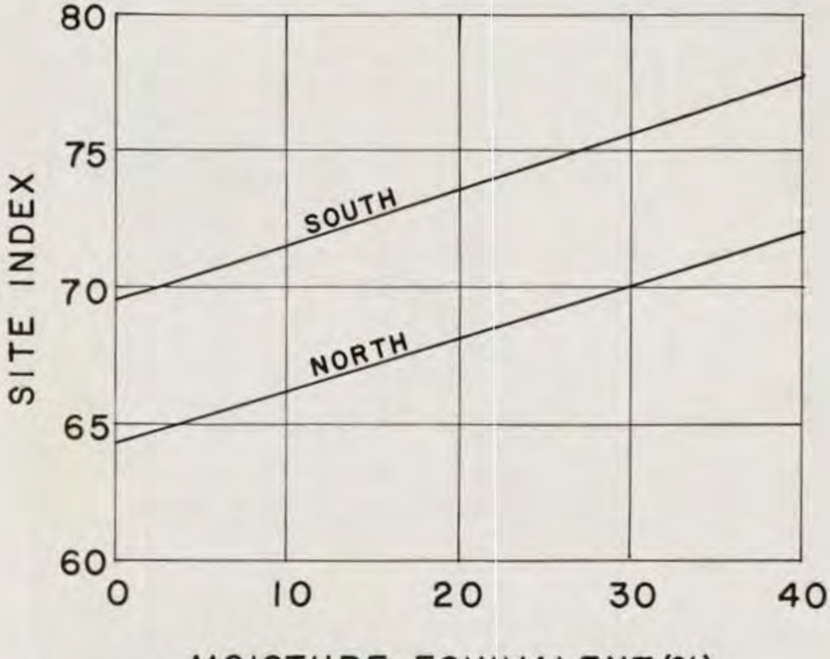

Figure 4—Site index of longleaf pine on well-drained soils as influenced by moisture equivalent and latitudinal distribution (from Ralston, 1951).

TABLE 6. SITE INDEX OF LONGLEAF PINE ON POORLY AND IMPERFECTLY DRAINED SOILS IN THE SOUTHEASTERN COASTAL PLAIN AS INFLUENCED BY SOIL CHARACTERISTICS (from Coile, 1952).

Subsoil characteristics	Depth to mottling		
Texture	Inches		
	18	30 Site index	48
Sand	59	62	67
Loamy sand	60	63	69
Sandy loam	62	66	71
Sandy clay loam	64	68	74
Sandy clay	67	70	76
Light clay	69	72	78
Heavy clay	71	74	81

The site index for longleaf and other species of pines has been related to soil series and mapping units used by the Soil Conservation Service in southeastern Louisiana (Linnartz, 1961, 1963). Also, Linnartz (1963) developed a regression equation for longleaf pine in this area, accounting for 26 percent of the total variation in site index with a standard error of estimate of $\pm$ 4.8:

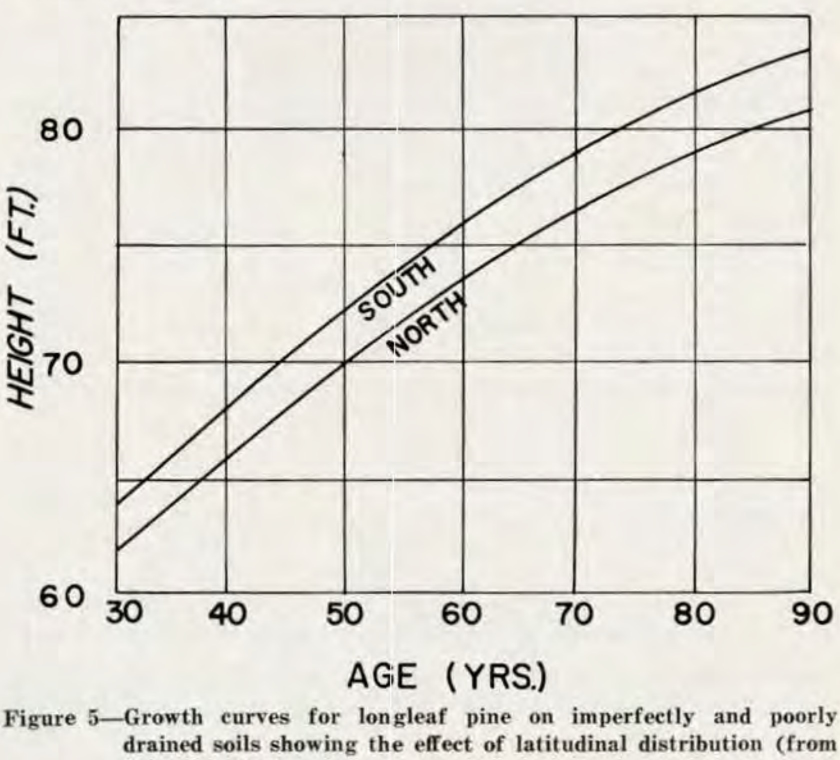

Figure 5—Growth curves for longleaf pine on imperfectly and poorly drained soils showing the effect of latitudinal distribution (from Ralston, 1951).

$$SI = 94.58 - 0.2174\ (SB) + 0.004918\ (SB)^2 - 1.083\ (SD) + 0.01885\ (SD)^2 - 0.1345\ (S1)^2$$

where SB = percent sand in the subsoil,
SD = degree of surface drainage,
and S1 = percent slope.

Trees in the southern portion of the range along the Atlantic Coastal Plain have higher site indexes than those in the northern zone (Figs. 4 and 5). Generally, this effect is included in the calculated estimates by adding 1 foot to the curve values of Fig. 6 for stands in Georgia and Florida and subtracting 1 foot from computed values for the Carolinas.

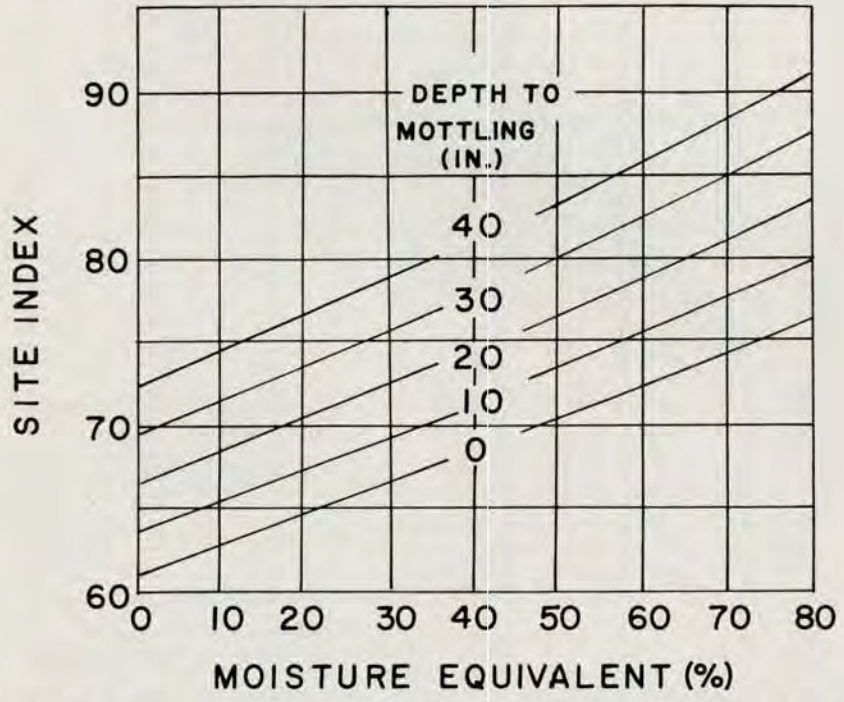

Figure 6—Site indexes of longleaf pine on imperfectly and poorly drained soils as affected by moisture equivalent and depth to mottling in the southeastern Coastal Plain (from Ralston, 1951).

Turpentining Effects

Turpentining has an influence on growth (Fig. 7). Round trees grow faster, and more so in the southern than in the northern part of the range. Statistically, the influential relation is limited to well-drained sites; but Ralston (1951) ascribed the lack of significance of turpentining on the imperfectly and poorly drained soils to the paucity of naval stores operations for analysis on these sites.

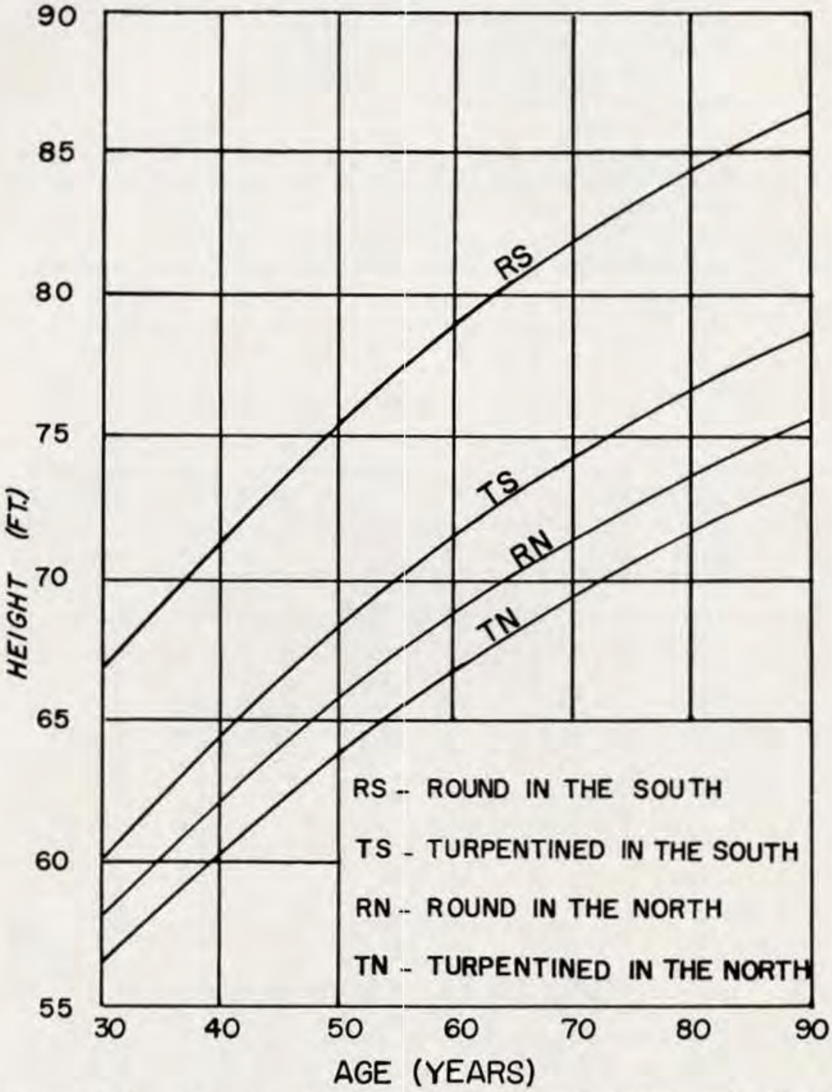

Figure 7—Growth curves for longleaf pine on well-drained soils of the southeastern Coastal Plain, showing the effect of turpentining and latitudinal distribution (from Ralston, 1951).

Southwest Alabama

Hodgkins (1956) tested Coile's tables in southwestern Alabama where soils are less poorly drained than in the Coastal Plain of the Carolinas. Adding 7 points to the table estimates is necessary. Hodgkins found McClurkin's table inadequate in southwestern Alabama, probably because drainage is good in contrast to the locale of McClurkin's study in the western Gulf Coastal Plain.

For southwestern Alabama, three longleaf site quality classes are proposed (Hodgkins, 1956):

(1) Poor: less than SI 65.

- a. well-drained, gravelly sands and coarse loamy sands more than 6 feet deep.
- b. well-drained soils with top soil severely eroded.

(2) Fair: between SI 65 and SI 74.
well-drained soils having subsoils with noticeable clay content (sandy loam or heavier texture) less than 6 feet deep; no mottling in soil profile; always on hilly land; lowest site index on ridge tops, best on mid-slopes with flat to concave configurations.

(3) Good: better than SI 75, but generally under SI 85.
imperfectly to poorly drained with heavy subsoil, on flat uplands, in coves, on lower slopes just above ponds and stream bottoms, and in branch and river bottoms; mottling is present except on flat uplands.

Also for longleaf pine plantations in the Alabama Coastal Plain, tree heights are correlated directly with age—soil characteristics apparently not exerting a measurable influence. Hence,

$$H = 2.44 + 2.385a$$

where H = height of tallest trees in plantations 8 to 16 years old, in feet,
and a = age, in years (Goggans and Schultz, 1958).

Hodgkins (1960) developed an arrangement of plant indicators to reflect soil moisture and thereby enable prediction of site index for longleaf pine in the middle Coastal Plain of Alabama. For instance, scrub oaks and goats'-rue occur on driest areas (SI 60); sweetgum, Indiangrass, blackgum, and bitter gallberry on sites of intermediate moisture (SI 84); and sweetbay, deergrass, and water oak on excessively wet sites (SI 74). Hodgkins considers this plant indicator scale about as reliable as soil-site and tree-site index determinations.

Johnson (1965) pointed out that all soil-site measurements provide are estimates of what the equivalent tree-site index should be, and it would be undesirable to have tree-site index rejected as a tool of the forest manager. He described a short-cut method which involves averaging the individual tree-site indices of the three to six trees of largest dbh on a fifth-acre plot. Tests indicated the procedure yields estimates of the actual site index that are sufficiently accurate for most management purposes.

Stand Density Effects

Increasing stand density 50 percent on SI 70 land increased mean height growth 6 feet. This is one of the few cases where height growth appears related to density, confounding measures of site potential. While Coile found well-stocked longleaf pine stands consistently with higher site index than poorly stocked forests, this is indicative of the limited capacity of the poor site to produce many tall stems, and not that site index is high because the stand is dense. Stocking-site relationships are not apparent for poorly and imperfectly drained soils of the southeastern Coastal Plain, nor in Louisiana (Russell and Derr, 1956; Roth, 1916).

Old-field vs. Forest

Chapman (1938) pointed out the importance of separating forest from old-field stands in calculating yield data. Hence, yield tables of Miscellaneous Publication 50 (Anonymous, 1929) cannot be used for data of combined stands less than 40 years of age. For instance, an old-field stand 15 years of age has, according to the curve, SI 76. From the table of the Publication, however, SI 92 is read. Yet, a 20-year-old stand of forest origin has SI 68 when read from the curve, but from the table only SI 74, considerably nearer the curve rating than is the younger stand. Stands originating in old-fields are faster growing in their early years due to less vegetative competition for moisture and, perhaps, nutrients while in the grass-stage (Ware and Stahelin, 1948).

Internode Measurements

The technique of Wakeley and Marrero (1958) for estimating past annual height growth from length of internodes has been found reliable by Curlin and Box (1961), the average error and standard error of the estimate being $\pm$ 0.28 and $\pm$ 0.36 feet, respectively, for observations ranging from 1½ to 5 feet. On trees 15 years old, 8 to 10 years' past growth can be estimated with ease, but accurate measurements are not attainable above a height of 40 feet.

Reproduction Establishment

Natural Reproduction

Longleaf pine natural regeneration has taken place on only a small portion of the land which, before cutting of old-growth forests, was in longleaf pine. Reproduction was difficult to establish because of (1) heavy cutting which left vast areas without a seed source, (2) infrequent seeding of the species, (3) cone insects, (4) heavy seeds that are not carried far by wind, (5) large seeds which do not get through the rough to the soil and which are favored food of birds and rodents, (6) prompt germination that results in heavy losses from winter fires, (7) hog grazing, (8) brown spot needle blight, (9) a long period in the grass-stage, (10) intolerance of shade and drought, and (11) fire exclusion which results in considerable vegetative competition. Under management, the degree of cutting, hog grazing, brown spot, competition, and fire are controlled.

Harvest Methods

Like other southern pines, 2 years are required from the time of pollination until cones are mature; but, unlike other species, seeds germinate shortly after dispersal in the fall, providing for root growth during the winter, and thereby affording some degree of tolerance against the hot, dry spells of the first growing season. Consumption of seeds by birds and rodents occurs over a short period.

As early as 1909, Chapman recommended a two-cut modified shelterwood, but later (1941) recommended either seed-tree harvests or minimum openings of 1 acre. Although growth of residual trees is poor, it is sometimes suggested that they be carried for another 40 years for high quality sawtimber and then be replaced by reproduction from the younger stand (Chapman and Bulchis, 1940). The resulting two-age-class stand, with an 80-year rotation, appears less desirable than a modified shelterwood, as early removal of seed trees under which seedlings are found is preferable to carrying them over a long period with lightning and windthrow mortality. Frequently, longleaf pine will come in as advance reproduction under stands that resemble the initial cut of a heavy shelterwood, a condition accidentally caused by heavy thinning, diameter-limit cutting or, less-likely, partial mortality from fire.

Observing this, Croker (1956) suggested it be simulated by opening stands 3 years before reproduction is desired, but leaving a fairly heavy overstory of 30 to 40 trees per acre. After an adequate stand of reproduction is established the overstory is removed, taking care to avoid logging damage (Fig. 8). This modified shelterwood is preferred to a seed-tree harvest because the long wait for a seed crop—up to 10 or more years—is avoided, less time is afforded for weed and undesirable hardwood inva-

Figure 8—These longleaf pine seedlings came in as advance reproduction under a stand that resembled heavy shelterwood. As soon as the seedlings were established, the overstory was removed (Croker, 1956).

sion, fewer birds consume seed than on open land, and stocking is sufficient to produce a reasonable per acre increment during the regeneration period. Although understocked seed-tree stands can produce wood at the rate of

6 percent per annum, this may amount to only 12 board feet per acre. Croker does not yet recommend this shelterwood method without further research to determine suitable preparatory cut densities, optimum removal cut technique, and methods to reduce logging damage. The importance of the latter factor was indicated by a study in southwest Alabama. Total seedling losses when clearcutting in second-growth were 51 percent when log landings were on the cut area and 33 percent when they were located elsewhere (Boyer, 1964).

Seed-tree harvests generally leave 4 to 8 well-spaced stems per acre. These should be 8 to 11 inches dbh and have 40-foot crowns. McMinn (1966) concluded that even with intensive site preparation, a minimum of 20 trees per acre is probably required to insure acceptable stocking under adverse weather conditions.

Seedbeds

Longleaf pine, perhaps more than other southern conifers, requires a mineral seedbed for best germination. Seeds germinate only where coniferous organic matter is decomposed. Where humus is appreciable, young seedlings fail to persist, possibly because of infection by damping-off fungi. Past the state of damping-off injury, high rates of organic matter in the mineral soil have little detrimental influence and may actually stimulate growth through improved moisture-holding capacity and fertility (Ness, 1927). Grazed carpetgrass seedbeds are also good, although grazing following germination is detrimental. Hardwood leaf litter is not too unfavorable for germination, as the rapidly decaying leaves, which conserve moisture, do not exclude pines. Wiregrass and broomsedge are poor regeneration sites, for seeds germinating in grass tufts are unable to extend roots to the soil. Grazing effectively reduces depth of rough.

Stocking at the beginning of the second growing season following germination in a dry year in Mississippi was satisfactory only where prescribed fire exposed the mineral soil. On burned sites, 3 times as many seedlings (2,500) were alive as on unburned areas (Smith, 1961a), while burning or disking just prior to seedfall was three to four times better than a 3- to 4-year rough for reproduction establishment in northern Florida (Osborne and Harper, 1937). Scalping the seedbed just before seedfall more than doubled the first year catch of longleaf pine on a sandy site in southern Alabama (Croker, 1957).

Soil fertility causes height growth of seedlings to vary to a greater degree than does site preparation by burning (Bruce, 1951), but growth is hindered by a hard, dry, and impervious soil surface. Growth increases with increases in organic matter and water content of the soil, but decreases with increasing soil hardness. These criteria are usually related, a hard soil being low in organic matter and water.

Vegetative Competition

Longleaf pine seedlings suffer from scrub oak competition in both productive loamy sands and deep sands recognized as poor sites in the uplands of the Coastal Plain. Grass-stage seedlings released when 1 year old grow considerably faster than those not released for at least the first

5 years. Whether oaks should be controlled prior to seedfall is not confirmed, as weeds and grasses replace the deadened oaks as competitors for soil moisture, and possibly nutrients, by the time pine seedlings appear (Walker, 1954, 1954a). Some oaks should be retained for shade the first year to act as "nurse" trees, as evidenced in a 4-foot-deep sandy soil where seedlings under scrub oaks survived a late spring drought better than those in the open (Gaines, 1950). Competing oaks apparently do not utilize as much moisture as exposed soil loses through evaporation, and herbaceous competitors are absent under hardwoods. In poorly drained flatwoods sites with dense young stands, hardwood invasion is slow until pines are 40 to 50 feet tall and canopies begin to open, requiring 15 to 25 years. However, fire exclusion encourages conversion to slash pine under which waxmyrtle and laurel oak encroach in old-fields, while water oak and sweetgum invade land long in forests (Heyward, 1939).

Excessive density of longleaf pine at germination time, often approaching a million seedlings, severely inhibits growth of the seedlings to a degree equal that of ground cover and scrub hardwood overstories. Wahlenberg (1934) counted 200,000 per acre 8 years old. For optimum growth, grass-stage seedlings should be thinned to perhaps 2,000 per acre and the soil around the seedlings scalped. Height growth was doubled by denuding, even where stocking exceeded 100,000 seedlings per acre (SFES, 1934). Litter also "smothers" seedlings.

Figure 9—Longleaf pine seed trees can reduce survival and vigor of seedlings for distances of at least 50 feet.

Magic Circle

Longleaf pine seed trees in south Alabama reduced survival and vigor of seedlings for distances of at least 55 feet on good sandy loam sites as well as on poor sites characterized by deep coarse sands (Walker and Davis, 1956) (Fig. 9). In Louisiana, this "magic circle" was calculated at only 30 feet, seedlings within that radius dying even when in full sunlight. Loblolly pines, too, smother longleaf seedlings soon after the latter are overtopped (Chapman, 1948; Smith, 1955; Chapman and Bulchis, 1940). When brown spot needle blight was controlled, longleaf pine seedlings survived and started height growth near large pines and oaks in Mississippi. However, competition was severer in zones nearer the overstory trees, and oaks were more serious competitors than pines (Smith, 1961). Boyer (1963), in Alabama, also found growth, but not survival, of longleaf pine seedlings improved with distance from parent trees. For at least 7 years, seedlings under overstories ranging up to 90 square feet of basal area per acre survived as well as those with no tree competition.

With root competition for moisture, and perhaps nutrients, seed tree harvests generally should occur soon after seedlings are established—within 3 years, but delays up to 5 years will probably not seriously affect survival.

Small seedlings near seed trees remain vulnerable to fire, as the annual fall and accumulation of needle litter from the overstory increases fuel and, subsequently, the danger of mortality. Mortality increases with the amount of needles in the rough, smallest seedlings in the grass-stage suffering most (Davis, 1955). Survival after 5 years is not affected by either seed trees or hardwood overstory competition when litter from around seedlings is removed (Smith, 1955).

Flowers and Seeds

Longleaf pine flowering usually occurs between February and mid-March, although inland from coasts, it may be a week or so later. Some trees flower a week before or after others in the same stand, and stands a few miles apart vary. Pollen shedding in the spring for several species may overlap, resulting in longleaf pine conelets being fertilized by slash pine pollen and longleaf pines disseminating pollen to receptive loblolly pine conelets.

Longleaf pine female conelets are receptive to pollen when openings between the thin, sharp-edged scales are visible to the naked eye. After pollen passes through these openings, the scales close and their tips thicken to prohibit further sperm entrance (Wakeley and Campbell, 1960). Seeds begin to ripen between October 1 and 20, and ripe cones float in liquids of specific gravity of 0.88 (McLemore, 1959). Cones on a tree tend to ripen simultaneously, and there is a strong correlation between the order of cone ripening of trees in a stand for successive years (McLemore and Derr, 1965). No strong relation occurs between ripening time and latitude (Dorman and Barber, 1956). In south Mississippi sound seedfall ranged from 8400 to 46,400 per acre, beginning in mid-October, with 80 percent expelled by late November and the remainder by mid-February (Smith, 1961).

Seedlings as small as 1 foot tall, although 16 years old, have borne cones (Pessin, 1936). In a plantation of 1-0 nursery seedlings, one longleaf pine tree bore female flowers after its fourth year. Many trees had male and/or female flowers after the fifth year (Smith, 1966). Because longleaf pine cones mature and open without seed (Wakeley and Campbell, 1960), although rarely, this could confound cone counts preparatory to harvest cutting and seed collection.

Seed Prediction

Yields of full seeds exposed by slicing cones in half longitudinally can be estimated by the formula:

$$Y = 11.18 + 6.02X$$

where Y = total number of sound seeds per cone,
and X = average number of seeds per cone exposed in slicing.

At least 2 cones from each of 30 trees should be sampled. Gross estimates of pounds of seeds per bushel of cones are made by assuming there are 75 longleaf cones per bushel and 5,000 seeds per pound. If all seeds are sound, then 1 bushel of cones yields 1 pound of seeds when an average of 9 seeds are exposed in bisecting cones (McLemore, 1961, 1962).

Viability

To determine if longleaf pine seed is viable, embryos are excised and stained with 2,3,5-triphenyl tetrazolium chloride (TTC) by submerging for 2 minutes in a 0.05 percent solution. If viable, red color appears in an hour after removal from the solution and washing off of excess chemical. The red fades out in several days (Parker, 1953).

Full and empty seeds can be separated by flotation in *n*- pentane, which is not harmful to viability. Full seeds sink as readily with as without wings (McLemore, 1965).

Stimulation

Early release, at least 32 months before cones mature or a year before pistillate flowers are expected, stimulates cone production—quadrupled over an 8-month release in a south Alabama longleaf pine stand (Croker, 1952, 1956) (Fig. 10).

Seed Dispersal

Fair to good seed-tree regeneration requires at least 2000 cones per acre (Wakeley, 1947). Normally, regeneration by clearcutting is confined to stand edges as shown by a 50-year-old stand with an effective seeding range in adjoining openings of less than 2 chains. Thus, where more than 100,000 seeds per acre fall within a stand, 15,000 seeds would not be distributed beyond 130 feet. Satisfactory stands, however, are attained at distances of 500 feet from forest walls with unusually heavy seed crops, good seedbeds, and favorable winds.

Boyer (1958) devised an equation to permit estimation of seed dispersal from forest walls:

$$Y = \frac{A}{4^x}$$

where Y = the number of sound seeds per acre in thousands,
A = average seeding rate inside the wall, in thousands per acre,
and x = the distance from the wall of timber in chains (Fig. 11).

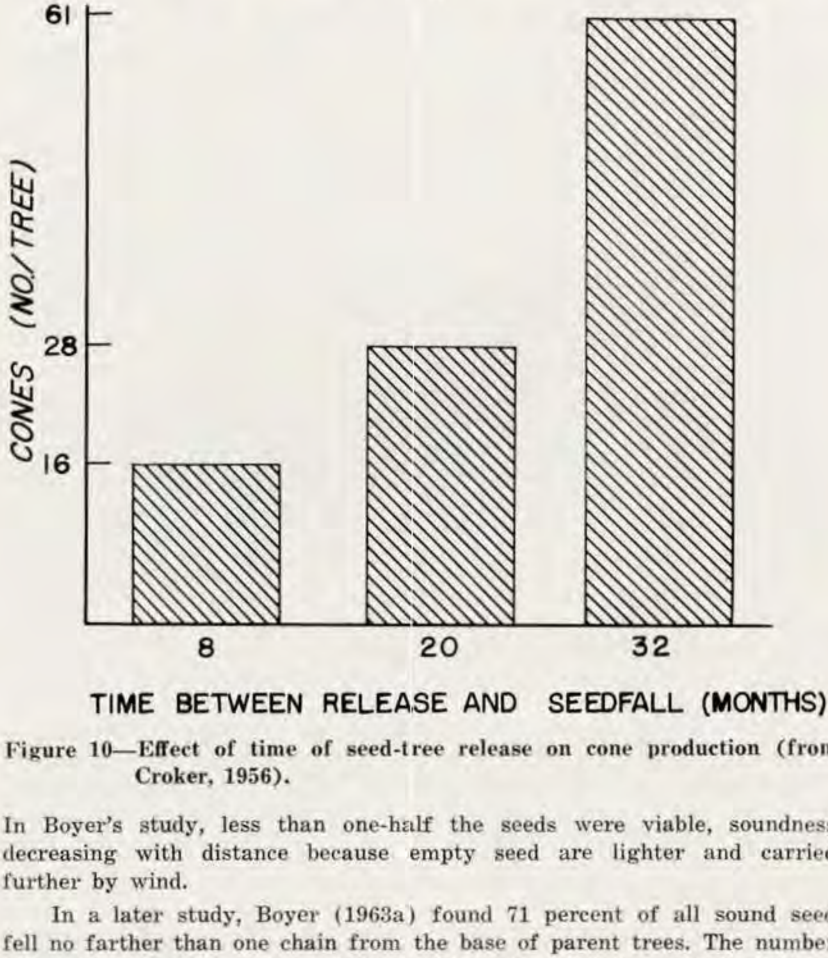

Figure 10—Effect of time of seed-tree release on cone production (from Croker, 1956).

In Boyer's study, less than one-half the seeds were viable, soundness decreasing with distance because empty seed are lighter and carried further by wind.

In a later study, Boyer (1963a) found 71 percent of all sound seed fell no farther than one chain from the base of parent trees. The number of sound seeds dispersed was halved with each 55-link increase in distance from the seed source.

Pests

Birds and rodents consume large quantities of longleaf pine seeds, frequently resulting in seed crop failures. In a test using various species of caged mice, all species preferred longleaf to loblolly, shortleaf, and

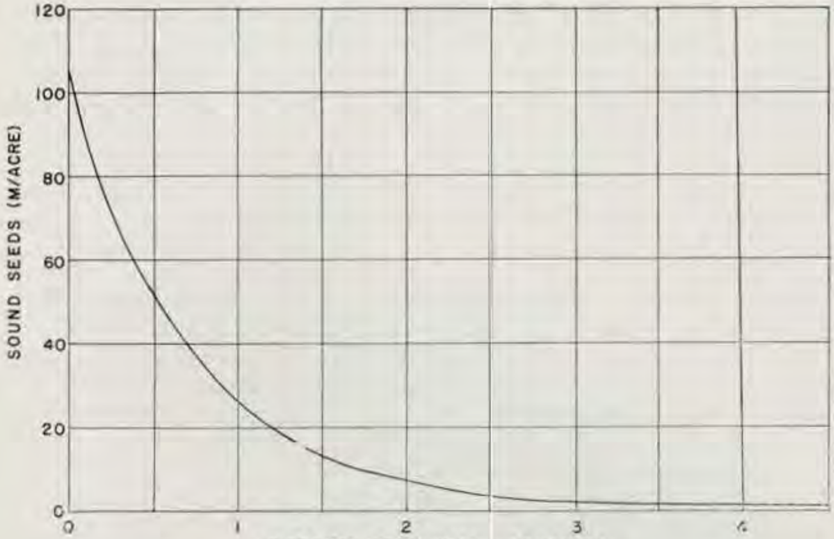

Figure 11—Longleaf pine seed dispersal (after Boyer, 1958).

slash pine seed (Stephenson, Goodrum, and Packard, 1963). Meadowlarks, juncos, sparrows (vesper and savannah), and blackbirds (Brewer's, red-winged, rusty, and cowbird) appear in longleaf pine areas only in good seed years while quail and mourning doves are more regular feeders. An autopsy of a single dove revealed more than 500 seeds in its craw. Mass movements of these birds in late autumn and early spring are governed by the availability of longleaf pine seed (Burleigh, 1938). More seeds are consumed in cold than warm Decembers because insects are then unavailable (SFES, 1938). Doves also pluck cotyledons after sprouting (Wallace, 1940). Bird damage may be less serious than frequently supposed on freshly burned areas, as the rough which follows protects seed (Bruce, 1949; Chapman, 1938).

A study in southwest Alabama showed that predators caused 93 to 99 percent of the seed and seedling losses during the first 3 months after spot seeding in November. Small mammals were responsible for an average of 58 percent of the losses; birds and large mammals, 33 percent; and insects, chiefly ants, 9 percent. Losses to mice peaked before germination and to ants afterwards (Boyer, 1964a).

Seed Germination

Longleaf pine seed germinates in autumn, 2 to 6 weeks after seedfall. Seed dormancy and the need for stratification are rare (USFS, 1948). This trait is of decided advantage with respect to initial establishment on deep sandy soils because the extensive tap root system can reach the lower levels of moist soil during winter and early spring before early summer droughts occur. In contrast, young slash and loblolly pine seedlings have to compete for soil moisture in the upper soil horizons with all other vegetation during periods when water availability becomes critical (Brown, 1964). Seeds germinate at temperatures of 50°F, although the optimum is about 64°F (Wakeley, 1931). Temperatures above 80°F may cause abnormal germination, seeds splitting open and radicles turning upward, a geotropic response not understood (McCulley, 1945). The germination of seed of high moisture content may be reduced by the fumigation with methyl bromide usually given lots that are exported or imported (Jones, Barber, and Mabry, 1964). Germination of seed is hindered by release before cones mature.

Summary

While reproduction of longleaf pine is not consistently obtained, a calendar of events for regeneration procedures in pure stands is outlined:

1. **Check seed production.** Cones should be counted in the spring prior to maturing. Since abundant seed crops are sporadic and as far as 10 years apart, rotations cannot be rigidly established, but must depend on seed supply. Seed production is sporadic because male and female flowers often are not synchronized in their development, resulting in pollen dispersal either before or after eggs are ready for fertilization. As 14 months are required for the sperm to fertilize the egg in the female flower, cones grow prior to completion of fertilization.
2. **Harvest by modified shelterwood cutting.** If sufficient cones are counted, the harvest is made between late summer and early spring. Thirty to forty uniformly spaced, productive seed trees are retained for subsequent stocking and insurance. Cones on trees felled just prior to normal seedfall will frequently open and disseminate seeds.

   An alternative is to wait until seedlings are established, and then clearcut the stand except for 30 to 40 stems per acre. This technique circumvents disadvantages of a seed-tree system, particularly in maintaining a well-stocked overstory until adequate regeneration is established.

   Croker suggests opening up mature stands to stimulate cone production while retaining considerable growing stock. Upon establishment of adequate reproduction, the overstory is removed lest it reduce stocking and vigor of the new stand (Table 7). Undesirable vegetation is thereby inhibited until pine stands are assured.

TABLE 7. SEEDLING STOCKING AS AFFECTED BY TIME AT WHICH ADVANCE REPRODUCTION WAS RELEASED (after Croker, 1956).

Years between seedfall and seed-tree cut	Stocking at age 1	Stocking at age 4	
		Advance reproduction	Seed-tree reproduction
	— — — — — Percent of milacres stocked — — — — —		
1	93	83	8
2	83	76	5
3	72	35	5
4	90	52	9

3. **Round-up hogs and cattle.** Hogs consume seedling roots in their quest for starch, and cattle trample regeneration.
4. **Prescribed burn.** Burning for "rough" reduction and to expose mineral soil should be done early in the winter, a year prior to germination, and just before harvest cutting. Scalping, a substitute for burning, removes grass and other understory plants as well as scrub hardwoods. It is particularly useful in ridges of deep sand (Croker, 1959).
5. **Determine germination and stocking.** Germination soon after seedfall enables stocking counts to be made during the dormant season, when grass and herbaceous vegetation do not camouflage seedlings and sprouts have not yet appeared as a result of the prescribed burn. Milacre stocking should exceed 70 percent.
6. **Survey for brown spot.** Strip surveys at the end of the second growing season ascertain if brown spot needle blight is serious. If less than 300 milacres per acre are stocked with healthy seedlings, treatment is suggested. Seedlings are unhealthy if over 30 percent of the foliage is infected.
7. **Prescribe burn for brown spot control.** If the survey warrants, a low-intensity winter fire, running fast with a steady wind is preferred. If blight infection is sereve, burning may be necessary every third year until seedlings are out of the grass-stage. Fast-moving fires do not kill grass-stage seedlings, a ring of needle stubs around the bud remaining unburned, and affording insulation. Once height growth starts—when seedlings reach an inch in diameter at the ground line—seedlings are very easily fire-killed and remain vulnerable until 4 feet tall.
8. **Determine stocking and survival.** Again, in the winter, milacre counts are made to determine if stocking is satisfactory (60 percent).
9. **Remove seed trees.** If stocking is adequate, the 30 to 40 residual trees are removed. Leaving the overstory longer than necessary for stand establishment results in stagnation and loss of seedlings near seed trees.
10. **Control overtopping hardwoods.** Delayed release reduces survival and growth, and the reduction of competition is more important for small than large seedlings (Table 8).

Sprouting

Grass-stage seedlings, and sometimes taller ones, may sprout if severed just above the root collar. Garin (1958) found more than 10 sprouts per tree, many of which were 6 feet tall.

Longleaf pine sprouts at the root collar if strong stimuli, such as fire, mutilation, fall fertilization, or *Cronartium* infection, are provided. Primary and fascicled needles are formed from axillary buds of lower primary needles. As longleaf pines above 4 inches dbh seldom have needles, and therefore buds, near the ground, sprouting rarely occurs on trees that large and is infrequent after height growth begins (Stone and Stone, 1954).

TABLE 8. NEED FOR REDUCTION OF COMPETITION, AS INDICATED BY DIAMETER OF YEAR-OLD LONGLEAF PINE SEEDLINGS (from Bruce, 1958).

Average groundline diameter (inches)	Probable start of rapid height growth with no brown spot	Competition reduction
0.10 - 0.20	5 to 10 years	Competition must be reduced if longleaf is to be regenerated.
0.25 - 0.35	3 or 4 years	Reduction of competition will generally pay.
0.40 +	2 or 3 years	Unprofitable to reduce competition, as seedlings are approaching maximum growth.

Artificial Reproduction

Planting

Poor survival of longleaf pine the first year after planting has discouraged its use in artificial regeneration. Much mortality is probably due to desiccation of seedlings before the root system—which has few laterals—becomes acclimated to the new site. Clipping needles of planting stock to 5 inches (needles average 15-20 inches long) at time of lifting, storing stock no more than 3 days between lifting and planting, and use of low-density nursery stock are suggested practices (Slocum and Maki, 1960; Allen, 1951, 1955) (Fig. 12). Defoliation usually does not cause mortality, but reduces growth by interrupting the storage of food that normally takes place in winter (Bruce, 1956). However, Derr (1963) found in one test that an early summer drought reduced survival of clipped more than unclipped seedlings and noted a small but consistent loss in vigor and growth of clipped seedlings in all three tests. He suggested that stock destined for good sites should be clipped only when the planter is willing to sacrifice some juvenile growth for the convenience of handling clipped seedlings. In contrast, McGee and Scott (1965) found clipping longleaf pine needles at planting time increased survival without decreasing growth. In addition to clipping, dipping in Dowax (⅓ quart per quart of water), which reduces transpiration by one-half, is suggested on a trial basis for difficult sites. On good sites, dipping only is satisfactory; for when accompanied by foliage clipping, stored foods and the capacity for their replenishment through photosynthesis are reduced. Roots must be kept free of wax (Allen and Maki, 1951).

Derr (1948) considered the fine lateral roots on planting stock important for absorbing water and nutrients, although tap root pruning is recommended for the Carolina Sandhills (Shipman, 1958), and Shoulders (1963, 1965) reported root pruning is a practical technique for increasing field survival of longleaf pine in Louisiana. The latter prescribed pruning in the nursery bed once at a depth of about 7 inches during October or November but at least 1 month before lifting. Root pruning to 3 inches sharply reduced survival in one study, but more moderate root pruning, to 5 inches, did not affect survival or growth (McGee and Scott, 1965).

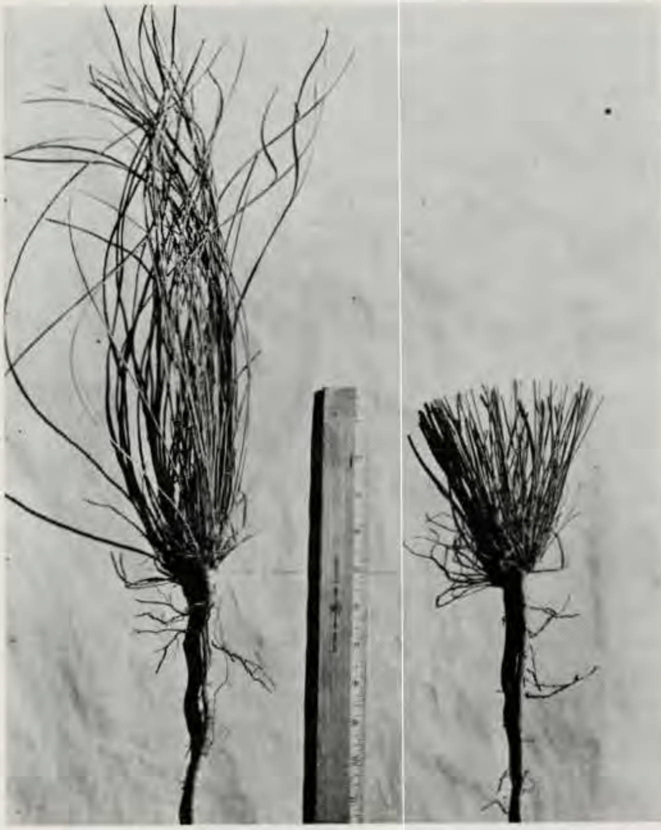

Figure 12—Clipped longleaf pine foliage increased first year survival 10 to 30 percent in some studies (from Allen, 1955; USFS photo).

Seedlings are planted in machine-made furrows 14 inches wide and 3 to 4 inches deep. The furrows protect seedlings from wind, improve soil stability, and maintain more favorable soil moisture than in unfurrowed sites. Soil moisture differences are greatest near the surface, but occur at lower levels, too. Initial survival on plowed sites is superior to that on those plowed and disked which—without berms—are desiccated by unobstructed wind just above the ground. Soil moisture was below the wilting point for 46 days during the growing season in unfurrowed sandy soils. Toward the end of the growing season, however, soil moisture is about equal on furrowed and untreated soils (Shipman, 1955, 1956).

If hardwood competition reduction is needed, complete eradication of competing vegetation is recommended by Bruce (1958). Where the cover is a rough, scalps of 1½ feet diameter or deep furrows are generally ample, except in deep sandy sites where even the wiregrass must be removed. Smith and Smith (1963) bar-planted 1-0 longleaf seedlings in a plowed and disked, deep sandy loam which had been in sod for a number of years. The plantation was cultivated three or four times per year, and

94 percent of the seedlings started height growth at the end of the second year. They concluded the main effect of cultivation was the conserving of soil moisture in dry periods so that growth continued through late summer and into fall. Removing competition may reduce fuel to the degree that prescribed fire for brown spot control is difficult and applications of bordeaux mixture are substituted. Fungicide sprays save half of a year's growth over fire which, of course, defoliates healthy tissues with the diseased; but this may be impractical.

Spacing at 6 x 6 feet provides adequate stocking where survival is poor, but 8 x 10 feet is satisfactory on favorable planting sites. Close spacing reduces fusiform rust as branch cankers drop off with naturally pruned branches before infections reach the bole (Mann and Scarbrough, 1948). Dense 4 x 4-foot spacings were recommended by Ware and Stahelin (1948).

Coastal Plain

Site preparation is prescribed for longleaf pine cutover lands on fine sandy loam soils in south Mississippi. Areas out of cultivation more than 2 to 3 years should be plowed. Muntz (1951) converted scrub oak areas in central Louisiana to longleaf pine by underplanting and releasing pines of all hardwoods soon after establishment.

In the west Florida Sandhills where longleaf pine grows naturally and once occurred in "fairly good stands," plantation establishment is difficult. Here, it is generally inferior to slash pine for planting. Although most longleaf pines that survive begin height growth by the end of the fourth growing season on prepared sites, Hebb (1957) reported stem elongation the second year. Clipping foliage may aid survival, but neither wax-dipping nor mulching with straw appeared effective.

Longleaf pine planting has been satisfactory in west Tennessee, but damage from sleet and snow generally preclude planting this species there (Williston, 1959).

Fall Line

The Carolina Sandhills, once supporting good stands of longleaf pine but now largely covered with scrub oaks, are difficult planting sites. Nevertheless, longleaf pine is the principal species employed in plantation establishment. For successful survival, sites are cleared with tractor-drawn equipment, allowed to rest for at least 6 months to stabilize the soil, and planted with highest quality nursery stock grown from seed of a local or upper Coastal Plain source. Foliage is clipped and roots pruned to not less than 5 inches. Where sprouting of scrub oaks is severe, seedling release is essential not later than the second growing season (Shipman, 1958).

Droughts cause seedling mortality. Although rainfall exceeds 45 inches per year, these deep sterile coarse sands are aptly called "deserts in the rain." Frequently 3 to 4 weeks without rain occur in summer; but within 3 days after rain, drought conditions may prevail.

Source of stock influences survival, and large stock, more than ¼ inch in diameter at the ground line, is best. Clay puddling of roots in a slurry of creamy clay mud just after lifting is a simple and inexpensive technique for guarding against injury from chance exposure. However, this species can endure up to 30 minutes exposure in air without clay puddling (Slocum and Maki, 1959, 1960).

Prescription planting, advocated by Hatcher (1957) in an excellent guide for the Carolina Sandhills, employs Grades I and II, 1 + 0 longleaf pine. Grade I stock is at least ¼ inch in diameter at the root collar; and has more than 12 inches of top (including foliage); abundant needles, in fascicles of 2's and 3's; and winter buds. Grade II seedlings have tops more than 8 inches long; stems more than 3/16 inch in diameter; needles moderately abundant, part of which are 2 and 3 to a fascicle; and lack buds with scales (Shipman, 1960). Top grade seedlings are most capable of enduring climatic extremes. Thus, while Grade I stock planted in spring is only slightly poorer than when winter planted, Grade II stock planted in spring is much poorer. Apparently small trees lack the vigor necessary to become established during the short interval between spring and the advent of the hot, dry growing season (Shipman, 1960). At the end of 5 years, the height growth advantage of Grade I over Grade II stock is about 2 feet, maximum heights being 13 and 10 feet, respectively (Fig. 13).

Soil characteristics may outweigh the advantage of vigor classes: Grade II stock on sandy loam is better than Grade I stock in sand. The most effective use of longleaf pine planting stock of either grade is on sandy loam soils planted in winter, when Grade II material may be used (Shipman, 1960).

The above statements apply to 1 + 0 stock. Older seedlings (1 + 1 and 2 + 0) are not superior in either survival or growth. Foliage clipping and root pruning are necessary when planting seedlings older than 1 year (McGee, 1961). Seedlings should be 1 + 0, from low to medium nursery bed densities—10 to 20 seedlings per square foot—and planted on prepared sites. (A crawler tractor with a triangular blade, which uproots and severs below the ground all scrub oaks, leaves the debris in place to aid in conserving soil moisture during the critical first year. Yet, because machine planting is more difficult after this treatment, undercutting is done several months in advance of planting to allow oaks to decay and to reduce first-year root sprouting. The land is left rough and the seedlings placed in series of broad V-shaped furrows 8 feet apart. Soil stabilization following site preparation can be hastened by pulling a bar across cleared sites at right angles to the direction of movement, or by single-furrow plowing.)

Fire is not a useful tool for eradicating scrub hardwoods in the Sandhills, as sprouting is prolific.

Old-Field vs. Cutover Forest

The contrasting development of longleaf pine seedlings on cutover lands and old-fields in south Mississippi was reported by Allen (1955a). Survival in the fine sandy loam soil was about the same; but at age 10, there were as many as 850 crop trees per acre in old-fields and less than 300 in cutover sites. Allen considered a crop tree at this age to be more

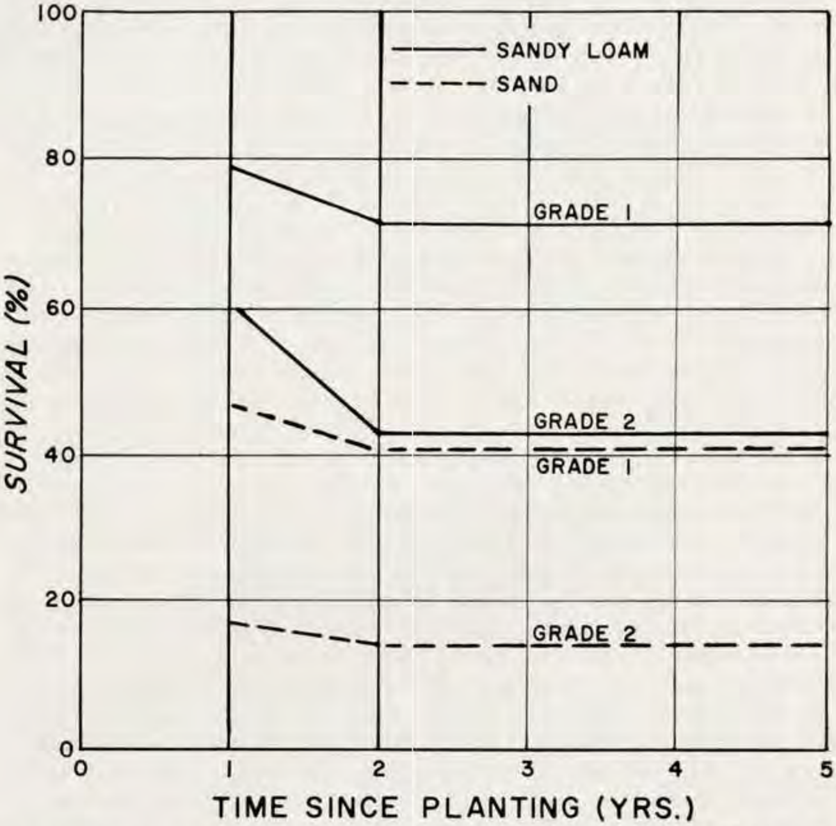

Figure 13—Survival of planted 1 + 0 longleaf pine by morphological grade and soil type (from Shipman, 1960).

than 3.5 feet tall and of good vigor; or less than 3.5 feet tall, but exceptionally vigorous and free of brown spot. Crop trees, averaging 18 feet tall, were 34 percent of those trees planted on old-fields. In contrast, crop trees averaged only 11 feet and comprised but 17 percent of the planted stand in cutover tracts (Fig. 14). Of course, at this age, one year would make an appreciable difference in the number of stems meeting the definition of a crop tree.

Direct Seeding[1]

The ease with which longleaf pine is direct seeded tends to reverse the trend away from the species' use in reforestation. With direct seeding, fine rootlets are not destroyed, as when nursery stock is lifted. Seeds should be sown when soil moisture is adequate (1½ to 2 inches of rain within the past few days) for prompt germination, and before migratory

[1]See Derr and Mann (1959) for guideline details.

Figure 14—Longleaf pine stands 11 years after planting 2,000 seedlings per acre on cutover land (above) and on an old-field (below) (from Allen, 1955a; USFS photo).

birds reach their peak in late December. (If feasible, seed should be covered by ¼ to ¾ inch of soil, especially on dry sites (Shipman, 1963). Jones (1963) recommended a ½-inch or less planting depth.) Late October or early November appears best in Louisiana. Although reported that as long as temperature remains high and insects fly, birds do not eat many seeds (Gemmer, Maki, and Chapman, 1940), it has been observed that seeds are the preferred food even of insectivorous species. Spring seeding is discouraged in the western Coastal Plain, as early droughts occur on the average every other year. Derr and Cossitt (1955) suggest using 10,000 viable seeds per acre, about 3 pounds of dewinged seeds with 70 percent germination capacity. This assumes 10 to 30 percent will produce vigorous seedlings. Eighty percent milacre stocking is usually achieved when 3,000 seeds per acre germinate. The goal for broadcast seeding is 2,000 seedlings per acre after the first year, and for strip seeding 1,500 per acre (Derr and Mann, 1959).

Early failures with stored longleaf seed led to the belief that direct seeding demands fresh seed, but Barnett (1964) showed that seed properly stored for 7 years can be successfully direct seeded. He recommended storage at subfreezing temperature and a seed moisture content of less than 10 percent. In addition, proper cone and seed handling is a prerequisite.

Site Preparation

First-year grass roughs following late winter or early spring burning are satisfactory seedbeds, as mineral soil is sufficiently exposed and some protection is afforded from rodents and birds (Fig. 15). Light roughs accumulate dew and reduce the drying effects of wind and sun. Fresh burns encourage birds and sometimes losses to rodents (Boyer, 1964); and roughs older than 1 year harbor high populations of rodents as well as obstructing germination. A heavy stand of second-growth old-field pine is much more effective than grasslands or scrub oaks in protecting seed from birds and rodents. On freshly burned rolling sites, erosion and washing dislodge seedlings before radicles enter the ground.

Disking a light rough the summer before sowing loosens the soil for radicle penetration. Grass competition is also reduced, especially important for improving first-year survival in a dry summer on a sandy site. Disked soil dries quickly after a rain, and light showers are often ineffective in restoring soil moisture; also, impeded natural drainage or reduced infiltration rate occurs with intense storms. To facilitate drainage, the soil is ridged in the final disking with strips at right angles to topographic contours. Some seed will be lost by silting, and brown spot needle blight of seedlings will probably be greater on disked plots than where burned. Strips, rather than whole fields, may be disked with lanes 8 feet wide and 6 to 8 feet apart.

In the South Carolina Sandhills, seed spots were unsuccessful due to rodent consumption of seed. Theft was greater for spring than winter seeding, and with wire screens pinned down, rodents burrowed or tipped the screens to get seed (Shipman, 1955a).

Several repellents have proved useful; Arasan 42-S is the best bird repellent found so far (Mann, 1965). In one test, Arasan-75 treatment adversely affected seed germination of all major southern pine species except longleaf (Jones, 1963). The same study indicated that seed users can store repellent-treated seed successfully up to 60 days at 38° F and up to 20 days at ordinary room temperatures.

Figure 15—Four-year-old longleaf pine established by seeding on a light rough. As brown spot infection was negligible, no prescribed burns were made (from Derr and Mann, 1959).

Scrub oaks on sites to be direct seeded should be controlled before or soon after seeding. Longleaf pine response to early release is sufficient to make the difference between adequate and inadequate stocking.

Genetics[1]

Seed Source

Seed source influences growth of longleaf pine, although one should be cautious in interpretation of early results (Wakeley, 1961), as demonstrated in the lower Coastal Plain of Georgia with stock raised from seed collected in Alabama, Louisiana, and Texas. Alabama Coastal Plain source seedlings were over 2 feet taller than an Alabama Piedmont source after 5 years, and almost 5 feet taller after 10 years. Two Louisiana Coastal

[1]Mergen, Rossoll, and Pomeroy (1955) and Wakeley and Campbell (1960) illustrate techniques for tree breeding and pollination control in seed orchards. Snyder (1961) discusses measurements of branch characteristics for scoring plus-tree selections in inheritance studies.

Plain sources differed significantly and one was considerably shorter than stock from Alabama or Georgia Coastal Plain provenances after 5 and 10 years. Survival did not differ in this test, but seedlings from Florida seed fail when planted as far north as Virginia. (Seed source significantly affected survival and height of longleaf pine in a 5-year-old plantation in central Louisiana (Shoulders, 1965a).) Forkedness varied significantly by source after 5 but not after 10 years. Although time in the grass stage and resistance to brown spot needle blight may be related to source, these are not predictable by latitude or longitude of seed provenance. Apparently, racial strains are associated with patterns of migration rather than with temperature zones, longitude, or other factors (Bethune and Roth, 1960; Allen, 1961; Collins, 1964). An exception may be indicated by the roots of seedlings from eastern Georgia seed which are more fibrous than those from seed collected further west, possibly because of wetter summers and autumns to the east (Snyder, 1961a). Ability to endure cold weather is probably associated with sugar and starch content of foliage (Parker, 1959).

Results of the Southwide Pine Seed Source Study after 3 and 5 years indicated that local seed is not always best, although nursery conditions may have influenced survival of seedlings and the erratic height growth of longleaf seedlings introduced much variation. To a certain extent, it appears that when local seed is not available, substitutes should be obtained east or west of the planting locality, rather than north or south of it (Wakeley, 1961).

Hybrids

Sonderegger pine is a hybrid of longleaf and loblolly pines named in honor of the State Forester of Louisiana by Chapman (1922) (for reasons not obscure to people familiar with their heated controversy on prescribed burning). Seeds of the cross, which breeds true, are from the longleaf pine parent; pollen from loblolly pine. As for longleaf pine, seeds germinate late in the fall, and there is one node in the main shoot of seedlings. The embryonic stage foliage, resin flow, and susceptibility to brown spot needle blight are also similar to that of longleaf pine. However, like loblolly pine, good height growth is made the first year and 3 non-persistent branches occur in a whorl at the end of the main shoot (Fig. 16). Buds and cones are intermediate to the two parents in size and appearance. Dorman (1952) reported tree form is poor and growth vigorous. Silvicultural practices allied to those for longleaf pine are generally recommended.

Slash pine x longleaf pine hybrids also occur. Harkin (1957) counted one tree with the typical longleaf pine grass-stage habit to two trees which made good early height growth of 1 to 4 inches the first year. Seven-year-old hybrids planted in central Louisiana demonstrated desirable characteristics of both parent species, resembling longleaf pine in form and branching habit but starting height growth immediately and growing almost as fast as slash pine. They appeared less susceptible than their parents to the brown spot needle blight of longleaf pine and the fusiform rust of slash pine (Derr, 1966).

Figure 16—Sonderegger pine, the loblolly pine and longleaf pine hybrid, 2 years of age.

Vegetative Propagation

Methods of propagating slash pine are satisfactory for longleaf pine, although a lower percentage of grafts "take" for the latter species.[1] The technique is imperfect, but cuttings from large trees have been rooted in the greenhouse by placing the bases in a solution of traumatic acid (15 ppm), pentachlorophenate (15 ppm), vitamin B (10 ppm), sucrose (5 ppm), and nutrients (not specified). Roots form in 10 weeks in sandbeds maintained at 85°F and watered 1 minute in every 10 (Dorman, 1947).

Disease

Cone rust of *Cronartium strobilinum*, the alternate host being oaks, damages longleaf pine seeds (Mathews and McLintock, 1958). Ferbam, at 2 pounds per 100 gallons of water, is recommended for control of the disease.

Intermediate Management

Thinning

Longleaf pine, while strongly expressing dominance, does not always respond to thinning. Influential factors probably include:

1. age of trees
2. vigor
3. pre-thinning growth rate
4. post-thinning climatic conditions
5. promptness with which new fibrous roots are put out to capture moisture and nutrients made available by removal of competitors
6. the ability of crowns to function with greater vigor even before these crowns have time to increase their leaf area (Chapman and Bulchis, 1940).

Cylindrical crown volume of 4300 cubic feet is required to produce 1 cubic foot of wood in fully stocked stands not released. Following release, however, only half this much crown space is required to produce the same volume. Chapman and Bulchis (1940) found that a 40 percent crown gives nearly maximum growth and, at the same time, the greatest clear bole length compatible with this growth, regardless of dbh.

Thinning for maximum yields of sawlogs in well-stocked stands should be such that the number of trees is reduced to 400 per acre. Typically this removes 3 to 5 cords in 100 to 150 merchantable stems when trees are about 25 years old (Smith, 1953, 1955a), assuming height growth begins at about age 5. Denser stands could be left if thinning is again anticipated within 15 years. Basal areas to leave are 75 to 80 square feet per acre for average sites—those on which well-stocked, evenly distributed stands may attain a basal area of 120 square feet. Such thinnings may be necessary as frequently as every 5 to 10 years. At age 60, 100 to 200 trees per acre should remain. Smith (1950a) suggests 75 to 100 final harvest crop trees. Poorly formed, naval stores "worked-out," diseased, cat-faced, stunted, and insect attacked trees are, of course, removed in thinning (Table 9).

[1]Johansen and Kraus (1958) detail methods for vegetative propagation.

Severe thinnings may result in hazardous wind storm conditions. Derr and Enghardt (1957) reported that longleaf pine stands reduced to 30 square feet basal area per acre lost one-half of the stems in a hurricane.

TABLE 9. LONGLEAF PINE THINNING GUIDE. BASAL AREAS INCLUDE ALL TREES 4 INCHES D.B.H. AND OVER (after Morriss, 1958).

	Leave basal area (sq. ft.) for site index—							
Age	40	50	60	70	80	90	100	110
20					51	56	60	64
25				52	61	66	71	74
30			50	60	68	74	78	82
35			55	66	75	80	84	88
40		46	59	71	79	85	89	92
45		50	63	75	83	89	93	97
50		52	66	78	87	92	97	100
55		54	68	80	89	95	100	103
60		56	70	83	91	97	102	105
70		59	73	85	95	100	105	109
80	44	60	75	87	96	103	108	112
90	46	61	76	89	98	105	109	113
100	46	62	77	89	99	106	111	114

Crown Length

Mortality begins when the crown length:height ratio approaches 0.1 and is imminent when the value is fully reduced to 0.1. Current dbh growth is about 0.1 inch per year for each 0.1 increase in the crown length:height ratio up to 0.4, at which point stands of saplings and poles give a steady, continuous average growth of 3 inches dbh per decade. No decrease in the amount of self-pruning is anticipated, for even when thinned, dominant trees in fully stocked stands self-prune to 40 percent of their height.

A crown ratio of ⅓ was maintained only in lightest density residual stands—those under 100 trees per acre. In 16 years, maximum growth in crown width was 8 feet, indicating that with 100 trees per acre (about 20 x 20-foot spacing) 30 years is required for stands to close.

Stem-crown diameter relations for longleaf pine are based upon the equation:

$$\text{dbh} = 2.39 + 0.62\ (C)$$

where C = crown diameter, in feet (Minor, 1961) (Fig. 17).

In Louisiana, thinning from above at age 20, making openings equal in width to dominant crowns, reduced the stand from 120 to 80 square feet per acre. Fifteen years after this severe thinning to 50 percent of the crown canopy, a net loss of 20 percent of the pulpwood yield resulted. Had this heavy thinning been delayed 5 years, the yield would have equalled that of unthinned forests 10 years later (Chapman, 1953).

Chappelle (1962), working in Georgia, developed guides for determination of future value growth rate for pulpwood based on tree characteristics, as crown ratio. He emphasized, however, that the effect of removing a given tree on the growth and development of nearby residual

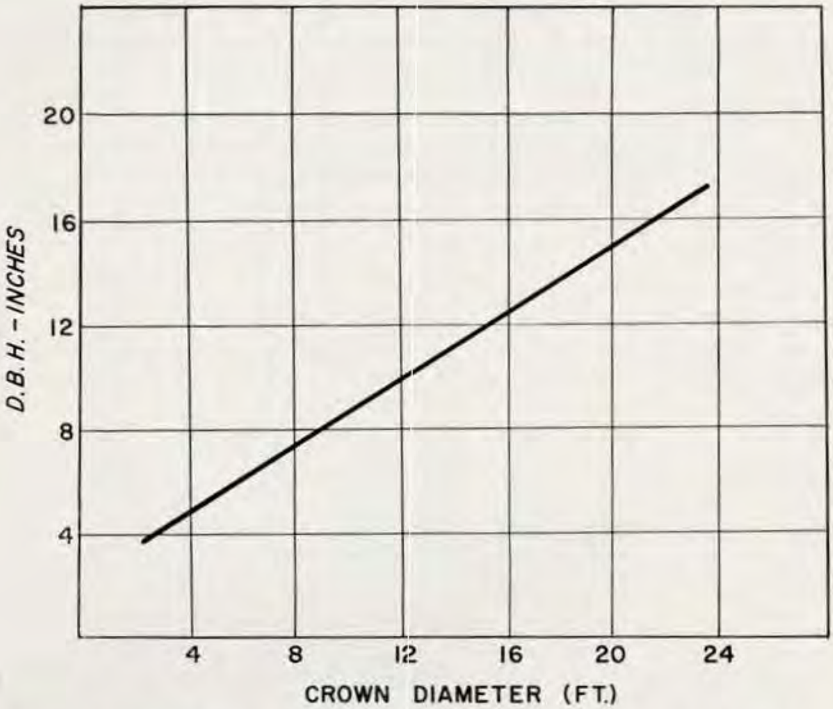

Figure 17—Relation of stem to crown diameters for longleaf pine (after Minor, 1951).

trees must be judged on the basis of silvicultural experience not adapted to formularization.

South Alabama

Reported results of thinnings have created "confusion worse confounded," as even data from the oldest longleaf pine thinning trials are inconclusive. Plots established in 1934 in two southern Alabama SI 70 locales were thinned to leave 200, 300 and 400 trees per acre at age 22. Unthinned check plots varied from 900 to 2800 trees per acre. The stands were fully stocked with a mean dbh of 4 inches and 100 square feet basal area per acre. For the first 15 years, Gaines (1951) cited no notable differences in growth for whole stands due to treatment. For the largest 100 trees per acre, however, thinning produced a 15-year mean gain in dbh of 3.4 inches on plots thinned to the lowest residual stand density of 200 trees per acre. Cubic foot yields 20 years later for all trees were least, but not significantly, where thinning was most severe. Basal area and volume growth, in contrast, increased with increasing stand density except for densest stands. Growth is probably more closely related to the number of trees per acre than to the basal area at age 22 (Fig. 18).

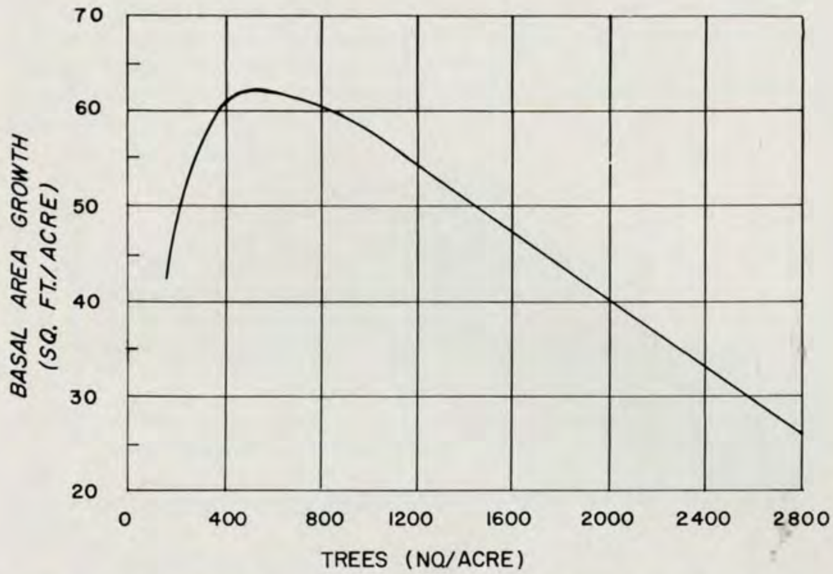

Figure 18—Fifteen-year basal area growth in relation to number of trees per acre at age 22 (after Gaines, 1951).

Optimum stand density at that age appears to be 1200 trees per acre, provided stands are thinned to leave 500 to 900 trees per acre. Another thinning at age 37 included the earlier check plots and left 40 to 350 trees per acre. Five years after this second thinning, growing space ap-

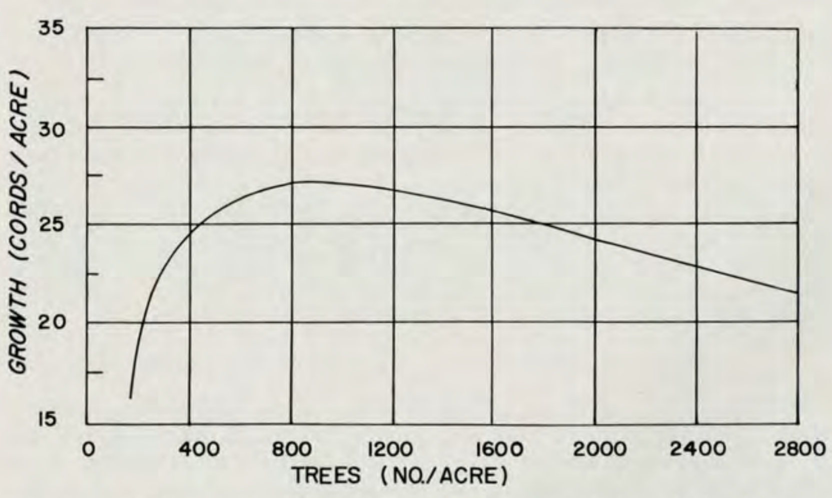

Figure 19—Fifteen-year longleaf pine volume growth in relation to number of trees per acre at age 22 (after Gaines, 1951).

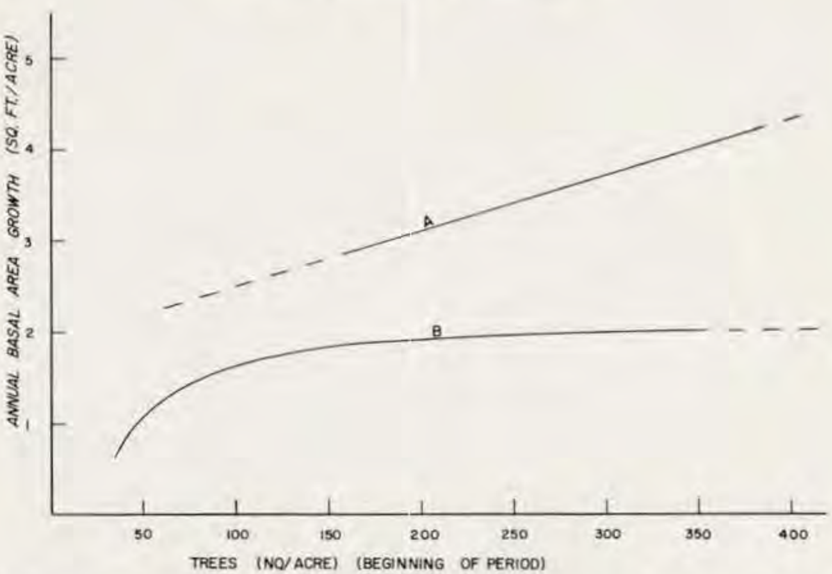

Figure 20—Periodic annual growth for natural longleaf pine stands (A) thinned to various densities at age 22, and (B) thinned and unthinned stand data combined. The curves represent growth during the period from age 22 to 37 years. Solid lines indicate limits of data. Check plots were not included in (A) since it seemed they belonged to non-representative populations. When check plots are not included in the regression analysis, a straight line with slope similar to that for younger age stands results (after Gaines, 1951).

pears related to periodic annual basal area growth and to the 5-year volume growth following both thinnings (Fig. 19 and 20).

Incorporating dbh in a multiple regression did not result in an appreciably improved indicator of growth over stocking alone. Greatest growth—basal area and volume—probably occurs in stands with more than 300 trees per acre when 37 years old, the number not known since the point where growth no longer increased is beyond the limits of the data. The heaviest thinning has, through age 42, been the least profitable, slight gain in diameter growth being attained but with considerable loss in volume yield. The point of diminishing returns for growth at age 37 appears to be about 200 trees per acre.

Northeastern Florida

On poorly drained sands underlaid with hardpan and accompanied by a low vegetation cover of saw-palmetto and wiregrass, maximum volume may be obtained over a wider range of stand density than is true for most other species. Leaving from 100 to 400 trees per acre on land with SI 65, at age 25, when trees were 4 to 6 inches dbh—sort of a pre-commercial thinning—made little difference. Annual growth of more than 1/10 inch dbh was obtained only when residual stocking was less than 65 square feet basal area per acre. Volume growth remained constant for basal areas ranging from 30 to 100 square feet per acre; but here the dbh growth of the 100 largest trees increased with decreasing basal area (Evans and Gruschow, 1954) (Fig. 21).

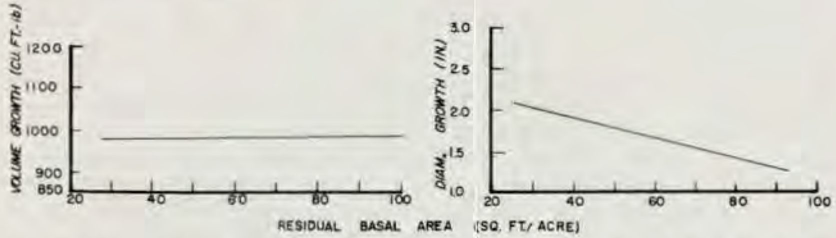

Figure 21—Sixteen-year change in cubic volume and diameter of crop trees of longleaf pine thinned from below to varying stand densities at age 25 to 35 years. Lines represent computed linear regressions (after Evans and Gruschow, 1954).

Longleaf vs. Loblolly Pines

Growth following thinning of longleaf and loblolly pines has been compared by Chapman (1951). Loblolly pine was on a site of slightly lower elevation and, therefore, because of better moisture conditions, slightly higher site index. Unthinned loblolly pine grew about 12 percent better in dbh than longleaf pine; but, when thinned, growth was 25 percent better for loblolly pine. Thinned longleaf pine dbh growth was 8 percent faster than in check plots, while thinned loblolly pine was double this. Board-foot yields were also less for thinned longleaf pine than for loblolly pine. Yet, Chapman believed longleaf pine would produce 15 percent more wood than loblolly pine if properly thinned, because the wider crowns of loblolly pine require removal of more trees to maintain a 50 percent canopy. Growth on the greater number of residual longleaf pines more than compensates for the slower growth on each stem.

Precommercial

Precommercial thinning, beginning with grass-stage seedlings, to reduce stands to about 3,000 stems per acre, often from 20,000, is advantageous provided milacre stocking is maintained at over 70 percent. Such thinning is especially appropriate in dense, stagnated stands on deep sands. Initial thinnings are made shortly after most trees begin height growth. Spacing of 6 to 8 feet between seedlings, leaving 700 to 1200 per acre, avoids stagnation (Gaines, 1951).

Competition Control

Roots

Root distribution of longleaf pine seedlings is especially important in the behavior of the species in seedling and sapling stands, and, in turn, root systems are influenced by soil moisture and structure and stand density (Pessin, 1939b). Apparently the early rapid tap root growth, curtailed when height growth begins, is related to nanism (Pessin, 1935). Paul and Marts (1931) found most roots in the upper 18 inches of soil. Pessin (1938a) noted that for 13-year-old trees still in the grass-stage, most roots are confined to the surface 6 inches. In contrast, broomsedge, wiregrass, and beggarweed roots extend to 8 inches and 3-year-old bluejack oaks produce extensive systems 12 inches deep and up to 7 feet laterally (Pessin, 1939b). Elsewhere, roots of longleaf pine and grass were both limited to the top 12 inches in a fine sandy loam soil, except for the conifer's tap root (Pessin, 1938a). Fibrous beardgrass roots form dense mats on the surface of the ground, or are hairlike, spreading in fan-shaped mats in all directions (Pessin, 1939b). Summarily, as roots of grass and grass-stage seedlings are in the upper foot of soil, removal of grass from around seedlings stimulates growth to a marked degree.

Pessin (1939b) observed the average depth of longleaf pine horizontal roots increasing with age, and tap and lateral roots reducing in length and number as stocking of young trees increases. The total root system of a longleaf pine at age 13 was 87 feet in contrast to 468 feet for a bluejack oak in fine sandy loam. In deep sands of west Florida, seedlings less than 3 feet tall had prominent tap roots, extensive horizontal systems, and vertical roots distinct from the tap, regardless of soil type. Those on well-drained sands were longest, those on poorly drained sites the shortest, and those on old-fields intermediate (Heyward, 1933). Roots ceased depth extension upon reaching the water table.

Soil type, however, may influence the length of lateral roots. Although form of initial root systems does not differ between clay and coarse sand if moisture is equivalent, the rate of downward growth depends on moisture in sandy seedbeds; in dry sands, primary roots develop to a greater depth in the same period than do roots in wet sands. Root growth is poorer in clays because the soil is dense—water is less available and aeration reduced (Lenhart, 1934). A 75-foot lateral root of a mature tree remained

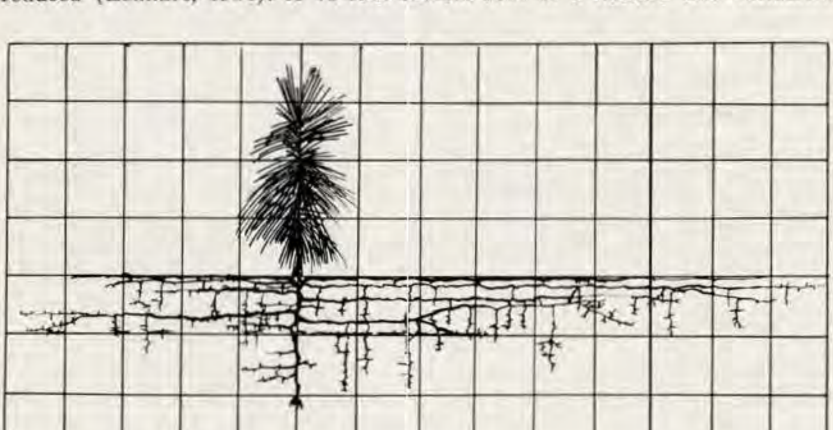

Figure 22—Transect of roots of longleaf pine in a poorly drained soil (from Heyward, 1933).

at a depth of 10 inches to a distance of 51 feet, then turned downward, ending at a depth of 3½ feet. While one root went around a turkey oak and then proceeded on its original course, most roots grow straight (Heyward, 1933) (Fig. 22).

Hough, Woods, and McCormack (1965) investigated the root extension of longleaf pine and turkey oak trees in the North Carolina sandhills utilizing radioactive iodine. Radioactivity was detected in pine stems as far as 55.1 feet from the source-plot center and in oak stems out to 48.7 feet; all pine trees within a radius of 17 feet from plot center and oaks within 15 feet showed contact with the isotope source. A similar study in a 24-year-old longleaf pine plantation in the same area showed uptake of I^{131} in all trees above 3.0 inches within 10 feet of the point of application; beyond 22 feet for surface applications and 33 feet for 1- and 3-foot depths, no I^{131} was detected in trees.

Roots make rapid growth in spring and autumn but make none in midwinter or midsummer (Pessin, 1939b). In contrast to slash pine, long-

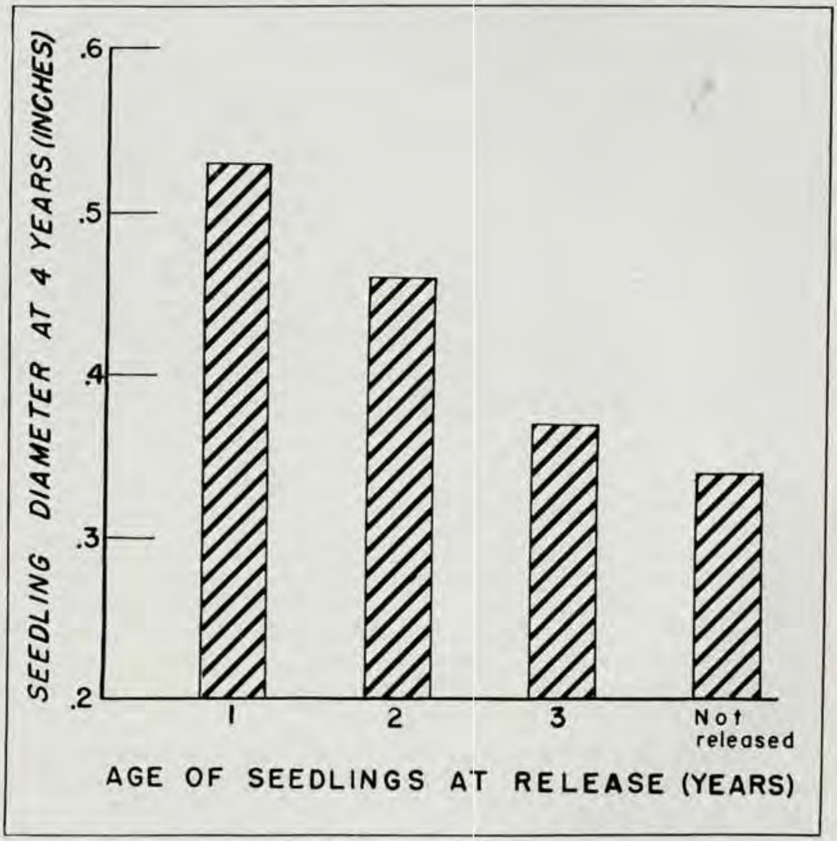

Figure 23—Release from hardwood overstories improves ground line diameter growth of longleaf pine seedlings (after Walker, 1954).

Figure 24—The 5-year-old seedling above was released from oak competition at age 1 and is now making height growth; the one shown on the next page was never released (from Walker, 1954).

leaf pine root length increases with increasing water in the soil beyond the 15 percent level, but growth and transpiration are greatest in moist (25%) but not wet (35%) soils (Pessin, 1938). The role of mycorrhizae and the conditions which influence their presence on longleaf pine seedling roots are unknown (Pessin, 1935, 1939b).

Species Relations

Hardwoods competing with longleaf pine seedlings for soil moisture, and possibly nutrients, must be removed (Fig. 23). In terms of both survival and growth, the best time for release appears to be during the first year after pines germinate (Fig. 24). While site quality made no appreciable difference in the growth of released seedlings, unreleased seedlings grew better on good sites than on poor sites, indicating early oak control is more effective on poor sites than on good ones (Walker, 1954). Control before seedfall is not desirable, as weeds and grass that replace the deadened oaks as competitors are well established when the pine seedlings appear. Smith (1955) noted that large oak trees could be retained for 5 or 6 years without serious mortality among reproduction, but height growth was retarded. In the longleaf pine-turkey oak type, all hardwoods should be controlled.

Forest Wall and Seed-Tree Effects

Forest walls retard longleaf pine seedlings in adjacent openings. These "walls" (border trees of timber stands) slowed the growth of seedlings as far away as 55 feet. The retarding effect far exceeded the reach of tree crowns, suggesting that longleaf pine seedlings tolerate shade better than root competition for water and, perhaps, nutrients.

When seedlings were 5 years old, root-collar diameters of those nearest the walls averaged 0.33 inch. The size increased 0.1 inch with each

10-foot interval up to 55 feet, enabling estimation of seedling diameters from the formula, $\frac{33 + \text{distance in feet.}}{100}$ This influence was more apparent for walls composed of trees larger than 11 inches dbh than for walls of smaller trees. Seedlings were equally retarded in deep sands and finer-textured, more productive soils. Near walls, one-half of the seedlings survived through the fifth year, gradually increasing to three-fourths at a distance of 40 feet (Walker and Davis, 1954).

Grass and Seedling Effects

As density of longleaf pine seedlings increases, from 1000 to 100,000 per acre, height growth and root development decrease both in grass and denuded plots. Best height growth is obtained where thinning to 1000 stems per acre is accompanied by grass removal. Denuding resulted in increased numbers of needles in fascicles on formerly dense plots, an evidence of good vigor. Height growth was substantially improved, more so where seedlings had been thinned than where grass was removed (Pessin, 1938a, 1939, 1939a).

Dry weight of pines in pots was greater where grass was removed, burned, or clipped, or seedlings watered than under untreated conditions (Pessin and Chapman, 1944). In field studies, however, fertilizing (400 pounds per acre of ammonium sulfate), watering, mulching, and combinations of these treatments failed to influence seedling growth, but grass removal did (Pessin, 1942). On a well-drained ridge covered with broomsedge, cultivation did not improve seedling growth but, again, scalping did (Pessin, 1944).

Scalping 2 to 3 feet around seedlings may be necessary. Removing grass from around longleaf pine grass-stage seedlings releases soil moisture and, possibly, nutrients for seedling use, although evaporation from the surface soil tends to hold soil moisture in check on denuded plots. Increased soil moisture is probably in the 6- to 12-inch soil depth, as there only did Pessin (1938a) find differences during 3 growing seasons which favored denuded plots. The retarding effect of grasses is greater on poor than on richer soils (Pessin, 1939a). Interestingly, but at variance with most other observations, Pessin (1938a) did not consider competition for soil moisture as an explanation for the slower growth of pines in the grass plots, for at no time during his experiment was the moisture content of the soil critically low. Indeed, much of the longleaf pine region receives more than 60 inches of rainfall per year. But while rainfall may be evenly distributed, a few hot summer days without rain can produce drought conditions in deep soils on slopes slightly inclined to the southwest. Pessin's assumption may be based on evidence obtained with methods lacking in sufficient sensitivity for moisture measurements which accurately indicate water requirements and deficiencies for plants.

Pessin noted that where grass was burned and ashes remained, the dry weight of pines was nearly as great as when sites were denuded, indicating perhaps that competition between grass and pines is principally for nutrients (Pessin, 1939a). Bruce (1958), however, found removal of ashes did not affect seedling growth; but where logs were burned, preventing grass from encroaching for a year, pine seedlings grew rapidly.

Where heat from solar radiation critically dries sites, shading seedlings from March to October with a palmetto frond stuck in the ground adjacent to the tree increases its vigor (Allen, 1954). Perhaps, then, some palmetto should be retained in control treatments.

Treatment with allyl alcohol reduced grass and subsequently improved seedling growth. The herbicide, diluted 1:100 in water and applied at a rate of 1 pint per square foot of soil surface, is used after prescribed burns for site preparation and before longleaf pine seedfall (Bruce, 1958).

Gallberry

Gallberry, the most abundant of some 20 native and introduced members of the holly family in the Coastal Plain, is a principal competitor of longleaf pine on many sites. Because of its stoloniferous habit, it often grows in dense thickets over 100 years old. Seedlings are rare, although large numbers of seed are produced by pistillate plants every year. As few seeds or germinating seedlings escape depredations by birds, rodents, insects, fungi, and other agents, virtually all new growth originates from sprouts. Birds eat both fruit and pulp of gallberries during winter, but apparently few viable seeds are passed. Growth of sprouts starts in late February, is most rapid from mid-April to mid-May, and ceases in late October or November. Average growth of basal sprouts may exceed 20 inches, and for terminal twigs it is 9 inches in a single year.

New leaves begin appearing in late February—before shedding of the previous year's foliage is complete in May. Leaves on sprouts, slightly larger than leaves on older stems, may be held into the second summer.

Rudimentary flower buds appear in March and in about a month attain full size. Flowering was observed to be completed in May with young fruits on the pistillate plants ripening gradually during the summer. The berry-like drupes turn black in August, persist until the following spring, and begin to fall when new growth starts. Ripened fruit averages ¼ inch in diameter and contains 2 to 9, usually 6, flattened nutlets. Plants killed back by fire bore neither flowers nor fruit until the second year (SEFES, 1960).

Pruning

Well-stocked stands of longleaf pine are self-pruning. Open-grown trees require pruning to improve sawtimber quality, as branches may persist for 25 years. For a clear butt log, trees are pruned to 8 feet when 16 to 20 feet tall, and again 6 to 7 years later. Greater efficiency may be realized by a single treatment to obtain 2 clear logs when trees are 34 feet tall.

While pruning up to one-half of the total height of saplings does not affect growth, pruning to a greater severity reduces diameter growth. Complete pruning of lateral branches on 4-foot-tall trees reduced growth during the 15 years after treatment by 0.2 inch in diameter for each foot in height. Pruning two-thirds of the total height reduced diameter growth half as much as complete branch elimination (Bruce, 1954). Stems 18 years old pruned of the lower three-fourth branches grew less than 3 inches the following 10 years in contrast to growth of 5 inches for unpruned trees (Marts, 1951).

A study on trees 2 to 8 inches dbh showed those pruned 40 percent of total height had growth reduced 23 percent; those pruned to 90 percent severity, leaving only the leader, had diameter growth reduced 87 percent (SFES, 1938a). Bull (1943) found clearing one-third of the total height results in a loss of 0.4 inch dbh or 1 year's growth. For short trees, a wide range in degree of pruning results in equal growth losses. That is, because a 9-foot open-grown tree generally has a 3-foot leader, severe pruning—even 50 percent—would remove virtually all of the crown. Yet, the additional crown quickly produced by a short tree is probably associated with the development of latewood which is dependent upon environmental factors present at the time latewood growth is initiated, in contrast to earlywood growth that is dependent upon reserve food stored from the previous growing season.

Wood-Quality

For trees pruned of branches on the lower ¾ of the bole at age 18, wood density below the lower crown limits was greater than before pruning. The earlywood increase from pruning is mostly in the first ring after treatment, but subsequently is decreased to less than that in unpruned trees. At a height of 12 feet in pruned trees, where pronounced reduction in ring width was exhibited, earlywood growth for 5 years after treatment was about 40 percent of the average ring width before pruning and 50 percent of the average ring width of untreated trees. Trunks showed reduced taper, as ring width at the upper limits of pruning was not affected by treatment (Marts, 1951).

Bud-Pruning

Bud-pruning, the annual removal of lower lateral buds and shoots, when applied to trees in a 20-year-old plantation resulted in better form, better quality, less taper, a higher percentage of latewood, and wood with average or higher specific gravity for its ring width than otherwise. The better form, or reduction in taper, is due to changes in earlywood:latewood ratio. The average earlywood width at lower levels is proportionally less of the total ring width than is latewood, and conversely at higher positions in the bole as a result of this severe treatment (Marts, 1950). This may be due in part to the effect of crown size on food production and storage, or to the possibility that conditions are more favorable for formation of soluble foods in the upper part of the crown where cell sap is densest and, therefore, more readily converted to cellulose early in the growing season.

Integrated Management

Range Management[1]

Ranging on improved pasture is more economical than is the supplying of protein concentrates for supplementing forest range. Nevertheless, forests are grazed, often to their detriment, in the interests of beef pro-

[1]Information in this section applies to longleaf pine, slash pine, and associated types.

duction. In much of the original longleaf pine forests, clearcutting and steam skidding took all large trees and knocked down small ones so that second-growth forests did not develop and a cover of bluestem grasses resulted (Fig. 25). Because cattle ranged Coastal Plain forests for over 300 years, their migration to these cutover areas was natural.

Figure 25—Clearcut lands now used for unimproved range (from Campbell, 1955; USFS photo).

Grazing animals trample seedlings, browse trees—mostly hardwoods, and with their hoofs expose soil to raindrop compaction and erosion. Too severe compaction results in stagheaded trees that are easily killed by fire, insects and disease. Bulk density and total pore space are expected to be less favorable under conditions of heavy grazing, especially on silt loam soils (Read, 1957). A ten-year study of grazing on silt loam soils in central Louisiana revealed soil compaction sufficient to restrict water movement into and through the profile, particularly during intense rainstorms (Linnartz, Hse, and Duvall, 1966).

Injury to young pine seedlings increases as new shoots develop in the spring. By late April, one-fourth of the seedlings planted on a native range had been injured (SEFES, 1959). However, seedlings can be protected by stocking adjustment, adequate distribution of water, and proper use of salt.

Favorable influences of grazing include soil exposure which provides a mineral bed for tree seed germination, consumed rough which reduces fire hazard, improved soil fertility through incorporation of manure with mineral soil, and undesirable hardwood control.

Forage Species

Dominant grasses in longleaf pine-slash pine forests of Georgia include pineland three-awn, Curtis dropseed, bluestems, panicums, paspalums, cutover muhly, lopsided Indiangrass, and toothache grass. *Andropogons* in Mississippi supply good forage only in the spring. *Axonopus compressus*, a carpetgrass of heavy soils, occurs on small burned and unburned areas. It is very palatable, well acclimated except for occasional dieback from frost or drought, thrives under concentrated grazing, spreads in competition with other native grass, and responds to fertilization.

Plants making up most of the cover in good southwestern Louisiana forest ranges include pinehill and big bluestems, switchgrass, Indiangrass, and swamp sunflower. Less frequent components of ranges in excellent condition, but which increase rapidly upon overgrazing, are the low panicums, cutover muhly, and slender bluestem. Plants invading under severe overgrazing and, hence, indicative of poor range conditions include broomsedge, bluestem, yankeeweed (apparently named circa 1865), eastern bitterweed, three-awns, and carpetgrass (Williams, 1952).

Grasses make up most of the yearlong cattle diet in Louisiana, palatable weeds forming 5 to 15 percent (Reid, 1954). While pinehill bluestem is grazed all year, slender bluestem is especially nutritional in spring and early summer until the wiry flower stalks are formed. On longleaf pine cutover ranges, 70 percent of the grazed grass is produced during the first half of the growing season, before the flower stalks are formed. Close repeated cropping at intervals of less than 4 weeks should be avoided as bluestem grasses are thereby killed (Cassady, 1953). Crude protein declines from 9½ percent in spring to 4½ percent in late summer. Ample quantities of calcium, potassium, and trace elements are found in the native forage grasses, but supplements of crude protein and phosphorus are needed for animal feeding (Duncan, 1958).

Browse

Browse plants of some importance to cattle diets, described by Halls, Knox, and Lazar (1957), include saw-palmetto, myrtle, sweetbay, blackgum, and summersweet clethra. All except saw-palmetto are seasonally grazed either in winter or early spring when they comprise 16 percent of the total forage intake. Very little browse is consumed in summer and fall. Indigestible lignin in browse is unfavorably high—over 20 percent, while digestible carbohydrate is low. Crude protein, however, exceeds that required for the average cattle diet, especially in winter. Calcium, copper, iron, and zinc are always adequate, and phosphorus and cobalt generally so (Halls, Knox, and Lazar, 1957).

Stand Stocking Effects

Herbage production in south Alabama longleaf pine stands increases rapidly as basal area decreases below 40 square feet. The increase is less rapid between 100 and 40 square feet. Herbs and forbs increase in stands

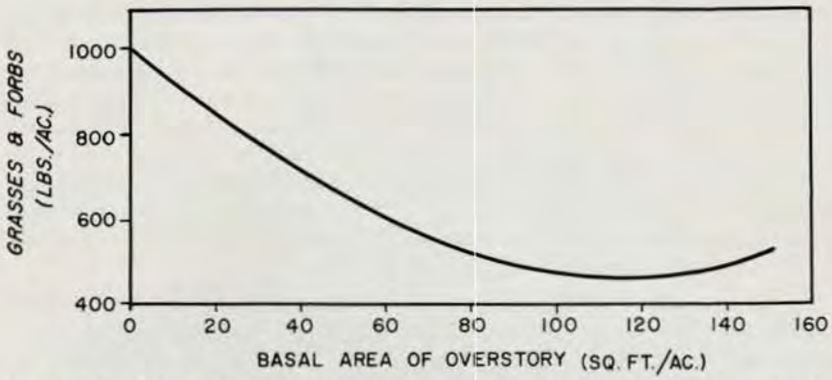

Figure 26—The influence of basal area on forage production in south Alabama (from Gaines, Campbell, and Brasington, 1954).

above 120 square feet per acre, probably because more light is penetrating the canopies, as such stands are generally older and have less trees (Fig. 26).

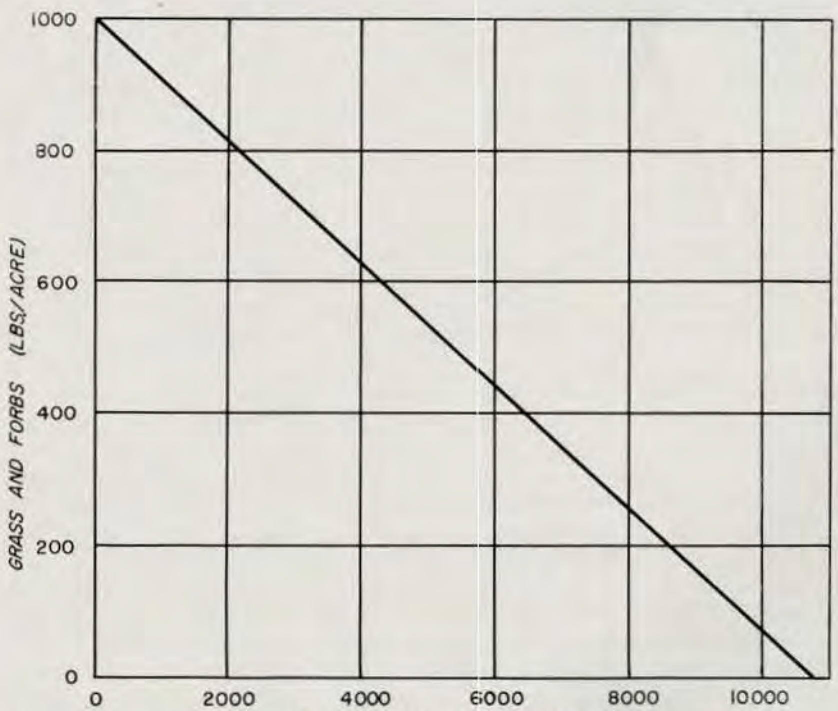

Figure 27—The amount of grass and forbs under pine-hardwood stands in the Coastal Plain decreases as the weight of accumulated litter increases (from Gaines, Campbell, and Brasington, 1954).

Gaines, Campbell, and Brasington (1954) found that the distribution of trees in a stand, more than basal area, affects herbage production. For instance, a single tree 7 to 14 inches dbh influences grass production up to 8 feet from its trunk, while a group of trees reduces herbage 30 feet from its edge. Only 14 percent of the decrease in herbage production was accounted for by basal area. Weight of tree litter, also influential, accounts for 20 percent of the variation in herbage production (Fig. 27). The grazing value of forests is negligible where 35 percent of the ground is shaded at noon (Shepherd, 1953), but this is not a very dense stand as shade in tight canopies is 60 percent or more at noon.

Cassady (1951) and Campbell (1951) reported 1500 to 2000 pounds (air-dry) of grasses per acre, principally pinehill and slender bluestems, produced in open forests of Louisiana and East Texas. Production is less than half under moderately heavy scrub oak stands and is further reduced under pole-size longleaf pine forests.

Normal grass production of 1000 pounds (oven-dried) per acre on open longleaf pine-slash pine forest ranges of Georgia declines consistently as overhead canopies increase from 5 to 35 percent, at which point basal area per acre may be expected to be over 90 square feet. As the

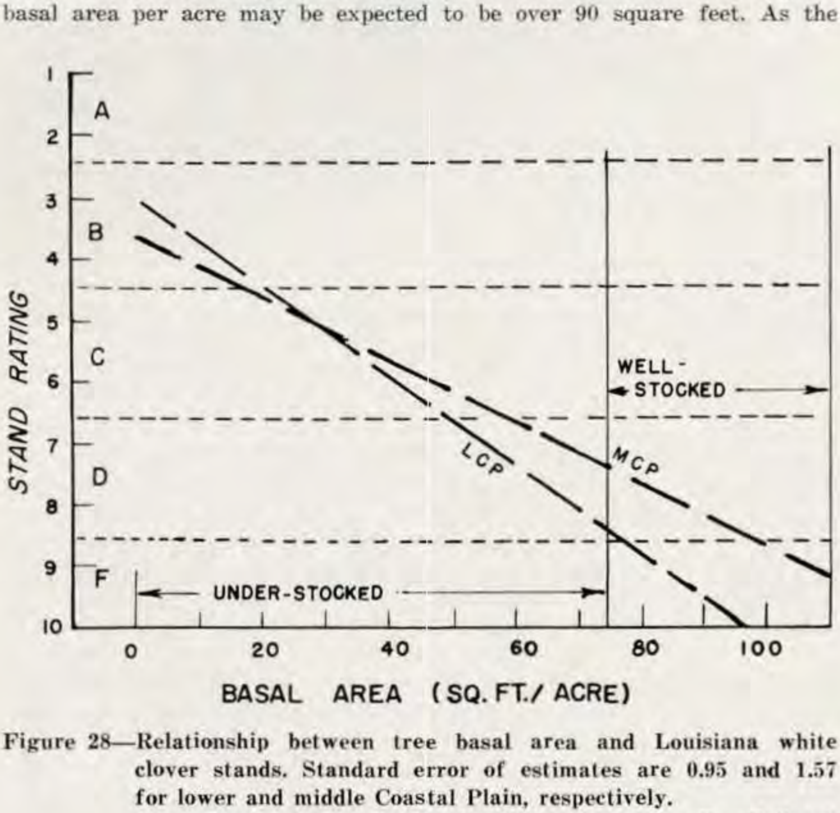

Figure 28—Relationship between tree basal area and Louisiana white clover stands. Standard error of estimates are 0.95 and 1.57 for lower and middle Coastal Plain, respectively. (A = Excellent, B = Good, C = Fair, D = Poor, F = Failure) (after Halls and Suman, 1954).

canopy closes further to 135 square feet basal area per acre, grass production levels off to about 300 pounds per acre (Halls, 1955).

White clover seldom persists where basal area exceeds 50 square feet per acre, and it grows rapidly only where basal area is less than 20 square feet. In the openings of thin stands, white clover succulence prevents the spread of winter fires. This legume does poorly in hot weather and is then killed by litter smothering (Halls, 1953). Where canopies are thin, especially in moist lowlands, white clover may be planted in the forest (Fig. 28). It should be fertilized.

Site Effects

Herbage production decreases as subsoil texture increases in coarseness. Thus, where subsoils are clay, herbage is over 800 pounds per acre in contrast to 500 pounds in deep sands (Gaines, Campbell, and Brasington, 1954). Better moisture-holding capacity of the finer-textured soil and, perhaps, perched water tables resting on hardpans that frequently occur in clay subsoils could be attributing factors.

Slender bluestem, particularly, is sensitive to moisture availability and thrives only where water is adequate. Yet, moist bottoms, even those in longleaf pine, are inferior for grass production due to heavy brush and tree competition. Forage growth varies greatly with annual rainfall and its seasonal distribution (Campbell, 1951), as wet summer seasons in unburned ranges produce 3 times as much forage as dry years, other things being equal (Smith, Campbell, and Blount, 1955).

Supplementary Feeding

Nutritive values of native range are far below maintenance levels for cattle in winter, adequate only for maintenance in summer and fall, and satisfactory in March and April when gains up to 2 pounds per head per day have been recorded (Campbell, 1946). Therefore, short-season grazing, from April 1 until cows stop gaining weight in midsummer, is recommended.

Supplementary feeding is essential, either with cut forage or by moving herds to improved pastures. Extra feeding is required in spring and summer for wet cows, as nursing cows require more phosphorus than acquired in mineral mixtures and native forage. A pound or two per day of cottonseed meal is a recommended supplement. Calcium may be deficient for lactating cows the first 3 or 4 months after birth, when lime requirements are high and the forage is low in this element. Dry cows and heifers make satisfactory gains and breed successfully on native range without supplements during spring and summer, although the critical point is approached much of the year, even when mineral supplements are added (Southwell and Halls, 1955; Halls and Southwell, 1954). Shepherd (1954) found protein and mineral content deficient most of the year.

In Louisiana, longleaf pine bluestem ranges had adequate minor elements for beef cattle. Only phosphorus and crude protein were deficient, the former in all seasons, the latter only in spring and early summer (Duncan and Epps, 1958). Because phosphorus levels are frequently inadequate, fertilization to increase the nutritional status is particularly desirable where burning is not prescribed.

Range Improvement

Prescribed Burning

Prescribed burning improves quantity as well as nutritional quality of forage. However, most benefits from burning disappear long before repeat burns consistent with good silviculture are made. Grazing may be continued on a reduced capacity for fire hazard reduction when stands close and prescribed burning is not harmonious with timber production. In longleaf pine forests, fire should be excluded until seedlings are in their second year of the grass-stage, or after they are over 4 feet tall. Between 1 and 4 feet, there is a 2- to 3-year period in which seedlings are very susceptible to fire injury.

In wiregrass ranges, prescribed burning results in better cattle gains without excessive tree damage. Forage "freshens" about 1 month earlier. However, in the reed forage type typical of pond pine forests of the Carolina Coastal area, prescribed fires delayed the growing season for range plants about 2 weeks, and reduced grazing capacity the following years. Fires make reeds more susceptible to subsequent death by grazing (Biswell, Foster, and Southwell, 1944).

Reid (1954) suggested burning every 3 to 5 years to get better cattle distribution. By that time woody, herbaceous, and total forage weights become about equal to those on unburned sites (Table 10).

TABLE 10. SUMMARY OF FORAGE PRODUCTION ON BURNED AND UNBURNED PLOTS (GREEN WEIGHTS IN POUNDS PER ACRE)
(after Lay, 1956).

Type of forage	First season after last fire		Second season after last fire		Third season after last fire	
	Unburned	Burned	Unburned	Burned	Unburned	Burned
Woody	675	524	848	743	794	606
Herbaceous	100	476	168	379	143	244
Total forage weight	775	1000	1016	1122	936	850

Spring is preferable to either autumn or winter for improving forage quality by burning. Lay (1957) considered summer burning equal to spring burning, but Lemon (1946) found short-term protein in range crops on early spring-burned areas two to three times greater than in summer burning. Shepherd (1954) noted that by October following spring burning, forage loses its palatability advantage and cattle graze unburned and burned areas equally.

Lemon (1946) was unable to burn in winter nights because of the high humidity, except with a 6- to 8-year litter. Such heavy mats of raw humus must be burned under moist conditions. Light litter is sensitive to humidity changes and, unless very low, it is burned in the afternoon. The constant wind direction and the ease with which fires burn out as the relative humidity builds up around midnight encourages night burning, employing backfires with winds at 4 to 7 miles per hour. On gallberry sites, backfires are prescribed, as headfires crown in waxy leaves of the shrubs, from which flames ignite tree crowns.

As cattle graze heavily on seedlings in burned areas where they congregate, distribution of stock and seasonal restrictions are essential to integrated range-forest management.

Soil Physical Properties

Grazing soon after burning is sometimes discouraged because the concentration of cattle on these areas causes soil compaction and trampling of reproduction. This is particularly true where incomplete burning has resulted in patches of lush herbage and where abundant tree reproduction has come in on temporarily exposed soil. Even on light soils, as loamy fine sand and sands, trampling after burning causes pronounced compaction of the upper 3 inches. Compaction increases with frequency of burns (Suman and Halls, 1955). While grazing slightly increases volume weight of unburned ranges, under burned conditions volume weight is doubled where grazed (Fig. 29). This results in poorer aeration, infiltration, and

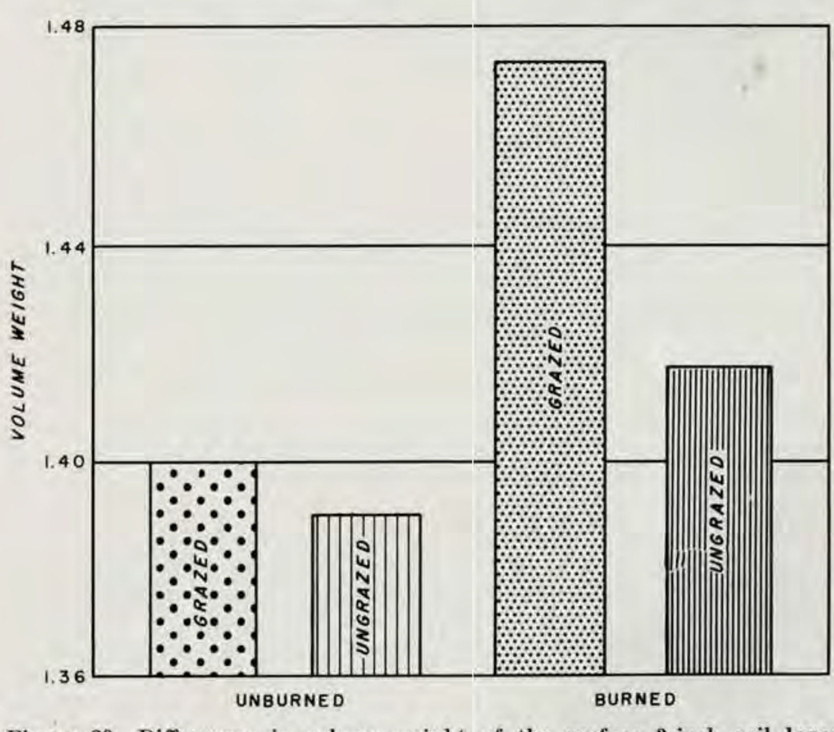

Figure 29—Differences in volume weight of the surface 3-inch soil layer between grazed, ungrazed, burned, and unburned sites (after Suman and Halls, 1955).

percolation, greater loss of rainfall through runoff and less water storage for use during drought.

Nutrition

Protein and phosphorus are 2 to 3 times higher and lignin content appreciably lower in the spring for forage burned the previous winter in contrast to unburned range. After grasses reach full leaf in June, the difference is not significant. Likewise the palatability advantage of burned tracts is lost by July (Shepherd, 1953).

Little bluestem is higher in crude protein and ash after burning. Phosphorus, calcium, and crude fiber are not significantly affected (Smith and Young, 1959).

In west Florida sandhills, where wiregrass is abundant in the longleaf pine-scrub oak type, grass is most nutritious in spring and on burned ranges. Where burned, calcium, magnesium, potassium, and sodium in the wiregrass are adequate for beef cattle, but crude protein is very the minimum required. Under unburned conditions, crude protein is very low and most minerals barely adequate. The influence of burning on wiregrass nutrition is shown by the following tabulation (Woods, 1959):

	Unburned (Percent)	Burned (Percent)
Crude protein	8.00	4.00
Phosphorus	.08	.03
Calcium	.91	.25
Magnesium	.07	.06
Potassium	.22	.22
Sodium	.10	.02

In East Texas forests, increases in protein after burning were more enduring than were phosphorus increases: 19 percent more protein the second winter afterward. There, the foliar nutrients of mulberry, sweetgum, and yaupon change greatly due to burning; water oak, muscadine, and viburnum change little; and dogwood, titi, ash, gallberry, blackgum, loblolly pine, and white oak are intermediate (Lay, 1957).

Apparently protein, phosphorus, and calcium, under some conditions, may be increased in forage, as mineral elements in dead organic matter are released and then taken up in subsequent plant growth. Soil pH may be increased as a result of the release of bases previously tied up in organic material (Halls, Southwell, and Knox, 1952).

Forage Production

Grass utilization is four-fold greater on burned than unburned ranges. Slender bluestem, especially, is grazed only sparingly on unburned tracts (Smith, Campbell, and Blount, 1955). The greater amount of annual grasses on burned than unburned sites may be partly due to the warmer soil—1° to 6°F—in spring where the black surface absorbs solar heat (Wahlenberg, 1937).

Range capacity with annual burning and continuous grazing was reduced by almost one-third, according to Halls (1957), as ground cover and grass yields are decreased. Where not grazed, however, frequent burning increases ground cover slightly. In southeastern flatwoods forest ranges, grazing and burning together increase brush, principally gallberry. Without burning, herbaceous ground cover is decreased, but it builds up rapidly for 3 years after burning to a peak of about 2 tons per acre (Shepherd, 1953).

Fire increased desirable legumes from just a trace to one-third of the ground cover in Louisiana (Reid, 1954). Light to moderate grazing complements fire by keeping down grass that hinders growth and seed production of herbaceous plants.

White clover, carpetgrass, and Dallisgrass are established without tillage in longleaf pine-slash pine forests when litter is removed by burning and the site subsequently fertilized and limed. The best forage occurs in openings where needle cast removal by fire enhances forage production (Halls and Suman, 1954).

Burning is useful in south Florida to reduce palmetto and to encourage nutritious range plants. Herbage increased from 66 pounds per acre 3 weeks after burning to 2200 pounds at 9 months and a maximum of 3500 pounds in the second year in one study (Hilmon and Lewis, 1962). The effects are short-lived, however, as palmetto resprouts vigorously and is apparently a fire subclimax species where ranges are burned no more than once in 2 years (Fig. 30). Except briefly after burning, palmetto is seldom eaten by cattle. Although burning and grazing appear to be ineffective control measures when employed separately, some combination may be useful in controlling or reducing palmetto dominance. Heavy grazing for 2 months following fire may eliminate it. Grazing subsequently removes sprouts and changes saw-palmetto lands to broomsedge-sedge dominance. Once palmetto is killed, stocking should be adjusted to facilitate maintenance of desirable forage species (SEFES, 1960).

Summarily, a period of no herbage volume immediately after a fire is followed by a brief period of low herbage volume-high nutritive quality and finally, by an extended period of high herbage volume-low nutritive quality (Hilmon and Lewis, 1962).

Fire Exclusion

Where fire is excluded for several years, a mantle of litter 2 to 3½ inches thick is formed. This organic matter smothers grass, provides food for soil animals, and results in greater A2 porosity. Soils with considerable clay fractions in the A2 produce crumb structure when protected from fire (Heyward, 1937). Curtis dropseed and pineland three-awns, which comprise one-half of the herbaceous cover in south Georgia, are adapted to persist after fire because leaf meristems, 1½ inches underground, are insulated by a tightly-packed mass of leaf sheaths. Both species are semi-evergreen perennial bunch grasses, their ligneous, decay-resistant litter suppressing other species (Lemon, 1949). "Fire-follower" species, the most important of which are bluestems, lopside Indiangrass, panicums, and trinius three-awn, are gone after 8 to 10 years of fire exclusion.

Figure 30—When saw-palmetto plants are burned, new leaves arise from the growing point deep within the stem. This growing point is not injured by the hottest fires.

Other Methods

In addition to prescribed burning, other methods for improving range in forest stands include:

1. Harvest by seed-tree method or clearcut and seed.

2. Prepare the site by clearing brush with heavy equipment, and seed with grasses. Dallisgrass is successfully established except in burned areas where it is crowded out by carpetgrass. Big trefoil is established with or without site preparation. Lespedeza establishment is not improved by site preparation, but is satisfactory on undisturbed sites following burning. Broadleaf herbs, such as goldenrod and dogfennel, may be troublesome where sites are prepared.

3. Fertilization is recommended for either (1) or (2). Minimal amounts for carpetgrass and lespedeza are 30 pounds per acre each of phosphoric acid (P_2O_5) and potassium oxide (K_2O) and 60 pounds each for Dallisgrass and big trefoil. Higher rates lessen the problem of broadleaf herbs (Halls, Burton, and Southwell, 1957).

Blackgum foliar analysis serves to indicate cobalt deficiencies for cattle in pine-hardwood forests. In Arkansas and Louisiana, 5 ppm or less of cobalt in foliage indicates the element is deficient for healthy cattle (Kubota, Lazar, and Beeson, 1960).

Grazing Capacity

Nutritional quality is more important than quantity of forage in determining carrying capacity on a year-round basis. That broadleaf browse is often of higher quality than herbaceous forage explains why cattle frequently prefer woodlands to adjacent openings.

Old-growth longleaf pine stands produce about 600 pounds per acre of range plants by July (Campbell, 1946). By October, more is available, but the grass is less palatable and less nutritious.

Grazing capacity for an 8-month season is determined by the formula:

$$\text{cow months} = \frac{\text{lbs. green grass}}{3000}$$

This provides 3000 pounds of green grass per month or 100 pounds per day, 40 percent of which is utilized (Campbell and Cassady, 1955). Grazing capacity during spring and summer should be based entirely on burned acreages, one animal for 50 to 60 acres being typical for well-stocked stands of longleaf pine.

For unburned wiregrass forests, Halls (1957) suggests managing cattle on the basis of an average of 35 percent utilization for optimum beef production. Thus, approximately 9 acres of good wiregrass range, yielding 1100 pounds of grass, provides ample feed for a 500 pound steer from March to January. Grazing capacity is adjusted downward as stand density and scrub cover increase, according to the equation:

$$Y = 1060 - 15X_1 - 13X_2$$

where Y = yield of herbage in pounds per acre,
X_1 = overstory cover in percent,
and X_2 = shrub cover in percent (Table 11).

TABLE 11. EFFECT OF OVERGROWTH OF TREES AND SHRUBS ON GRASS PRODUCTION IN LONGLEAF-SLASH PINE WIREGRASS RANGES (after Halls, 1957).

Shrub density	Tree overstory				
	None	5%	20%	35%	50%
Percent	Pounds of grass				
0	1060	985	757	530	292
5	995	918	691	464	226
10	930	852	625	398	160
15	865	786	557	332	94

Accordingly, where trees and shrubs are absent, the grass yield is 1060 pounds per acre per year (Halls, 1957; Halls, Hale, and Southwell, 1956). Halls assumes that grasses comprise 85 percent of the total diet of 13 pounds daily for a 500 pound steer.

In the south Alabama Coastal Plain, open areas producing 1000 pounds of air-dry grass and forbs per acre per year adequately support 1½ cow-months per acre per year. Moderately stocked areas with 90 trees over 4 inches dbh, basal area exceeding 100 square feet, and 5000 pounds of litter per acre on the forest floor produce about 500 pounds of herbage. This is satisfactory for ½ cow-month per acre per year (Gaines, Campbell, and Brasington, 1954).

For southwestern Louisiana, a suggested yearlong grazing capacity for a range in excellent condition with over 75 percent of the ground cover in desirable grasses and a tree canopy of 50 percent is one animal per 20 acres. It is one animal for 30 acres on poor ranges where desirable grasses make up less than 25 percent of the cover (Williams, 1952).

In summary, the carrying capacity of a forest range comprised principally of longleaf pine is about one animal for each 6 to 10 acres on newly burned land. This provides for good weight gains and perpetuation of favorable forage species (Lemon, 1946; Shepherd, 1954).

Goats and Sheep

Goats are worse than sheep, and sheep worse than cattle on soil, range plants and trees. Sheep should be excluded from longleaf pine stands in which trees are less than 4 feet tall, as most seedlings have terminal buds browsed, many two or more times, and some will be permanently deformed. Buds susceptible to injury are white and wooly, at least 0.4 inch long. Most damage occurs in winter and early spring when buds are abundant and succulent and herbs are scarce. Height growth is 25 percent less for grazed than ungrazed seedlings (Mann, 1947; Maki and Mann, 1951). Growing sheep on longleaf pine lands requires large blocks with evenaged management.

Hogs

Hogs, including razorbacks, have long been grazed in forests of the

South, particularly the regularly burned pine types (Fig. 31). These "piney woods rooters" do extensive damage to longleaf pine seedling stands in the spring after available oak mast has been consumed in swamps and bottoms. Pulling up seedling roots may take place for only a month in the spring—just until the ground is dry and hard (Peevy, 1953).

Figure 31—Longleaf pine was established naturally on either side of the fence. Unfenced hogs destroyed the seedlings on the left (USFS photo).

Hogs have destroyed all seedlings in some Louisiana stands, pulling up roots to depths as great as 6 feet (Chapman, 1948). Destruction of 6 seedlings per minute, 15 feet of root in 10 minutes, and ½ acre of seedlings per day by a single animal has been observed (Hopkins, 1947, 1949).

While it is popularly stated that hogs eat longleaf pine roots as a spring tonic or to kill kidney worms, it is more probably a diet of last recourse. Woods hogs of questionable ancestry are small, stunted, poor in conformation, and seldom fat. A rooter's livelihood depends on an ability to scrounge that which, when excellent, seldom produces an animal exceeding 150 pounds in 2 years. As hogs do not readily convert roughage to body tissue, they ordinarily obtain carbohydrates from concentrates low in fiber and high in starch like the tender bark of the longleaf pine root, the dry weight of which is 85 percent starch (corn is 80 percent starch). Bark also has low resin and fiber content in contrast to the bright, peeled root which is often left.

A 150 pound hog—and most woods hogs weigh less—needs 5 pounds of forage per day, 4 of which should be high in carbohydrates. As root bark is one-half water, 8 pounds of roughage per day, equal to 90 linear feet of laterals, 130 linear feet of taproot, or the roots of 210 seedlings are essential for sustenance (Hopkins, 1947). Obviously, then, hogs must be excluded from longleaf pine forests in which trees are less than sapling size. Fencing is frequently essential.

Grazed Firebreaks and Rights-of-Way

Extensive areas in firebreaks and rights-of-way can pay their way by grazing which, at the same time, reduces the fire hazard. If closely grazed most of the year, fuel is less flammable than on burned breaks, and erosion is less likely than in plowed lanes. It has been suggested that a herd of heifers ranging on a power line right-of-way from Florida to Chicago would be old enough and fat enough for slaughter upon arrival. Old enough is true, but whether fat enough would depend on forage quality and quantity.

To improve forage, a general rule for fertilizing rights-of-way and firebreaks is to apply 40 pounds per acre per year each of phosphoric acid (P_2O_5) and potassium oxide (K_2O), 50 pounds per acre of nitrogen, and 1500 to 3000 pounds per acre of lime if needed for adjusting pH to 5 or 6 (Suman, 1954) (Table 12). Nitrogen is applied shortly after periods

TABLE 12. SEEDING AND FERTILIZER RECOMMENDATIONS FOR PLANTS COMMONLY USED ON FIREBREAKS
(after Halls, Hughes, and Peevy, 1960).

Forage plants	Recommended fertilizer maintenance rates per acre			Recommended seeding or planting rates per acre
	N	P_2O_5	K_2O	
	Pounds	Pounds	Pounds	
Summer grasses:				
Carpet	40	30	30	10 lbs.
Coastal Bermuda	100	50	75	10 bu. sprigs
Common Bermuda	60	50	50	5 lbs.
Dallis	100	50	75	20 lbs.
Pangola	100	50	75	10 bu. sprigs
Pensacola Bahia	100	50	75	15 lbs.
Orchard	100	50	75	10 lbs.
Tall fescue	100	50	75	20 lbs.
Winter grasses:				
Ryegrass	75	50	50	35 lbs.
Oats	75	50	50	100 lbs.
Common rye	75	50	50	100 lbs.
Abruzzi rye	75	50	50	100 lbs.
Summer legumes:				
Common lespedeza	0	40	50	20 lbs.
Kobe lespedeza	0	40	50	20 lbs.
Winter legumes:				
White clover	0	50	60	5 lbs.
Crimson clover	0	50	60	20 lbs.
Sub-clover	0	50	60	20 lbs.
Ladino clover	0	50	60	4 lbs.

of active growth, and in midwinter for cool season annuals, as well as at planting time. Thus, doses are split 5:3:5:3 for spring, summer, fall, and winter applications. Phosphorus and potassium are applied once in the fall.

Two plans have been recommended for preparing firebreaks (Halls, Hughes, and Peevy, 1960):

1. Disk, harrow or drag to level the land and allow 6 months to a year for woody material to decay and soil to settle on low-lying areas. This also helps to achieve firm seedbeds which forage plants require.

2. Burn and fertilize, then eliminate bunch grass induced by these treatments with close grazing for 2 to 3 years. Sod-forming grasses and seed legumes such as white clover and lespedeza usually invade.

Vegetation

In either plan, grasses palatable to cattle, such as carpetgrass and Dallisgrass—both for summer forage—are seeded, or coastal Bermudagrass is sprigged. Dallisgrass resists the spread of fire, but it is restricted to moist sites. Although coastal Bermudagrass is very productive on a wide variety of soils, endures drought, and uses fertilizer efficiently, it retards fire poorly. No species is satisfactory for retarding fire during the period from mid-October to mid-November (Fig. 32).

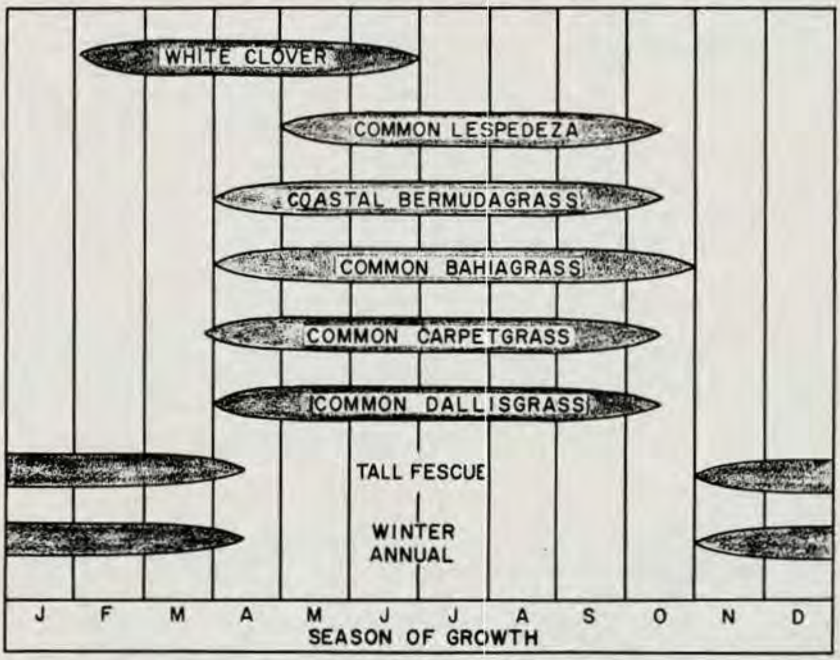

Figure 32—Forage species providing adequate new growth for satisfactory fire protection except mid-October to mid-November (from Suman, 1954).

On upland sandy soils in the Southeast, combinations of coastal Bermudagrass, annual lespedeza, any winter annual grass, crimson clover, or adapted reseeding legumes are satisfactory. On more moist sites, Dallisgrass, annual lespedezas, winter annual grasses, and white clover are appropriate. In the western reaches of the region, carpetgrass replaces coastal Bermudagrass in upland sites. In the North Carolina Coastal Plain, Dallisgrass, tall fescue and ladino clover are suggested on moist sites, while on similar soils in Florida, Pensacola Bahiagrass, annual lespedeza, oats or rye, and white clover combinations are appropriate (Halls, Hughes, and Peavy, 1960). For the Coastal Plain in general, Halls and Suman (1954) recommend white clover for protection from January to May, and Dallisgrass from April until autumn frosts, applying 4 to 10 pounds of seed per acre, respectively. Palatability, attributes, and adaptability of potential forage plants under conditions of drought, flooding, and fire are given in Table 13.

Grazing Capacity

Firebreaks and rights-of-way intensively managed will carry 1 cow on ¾ to 1 acre, depending on the amount of fertilizer used, the stand of grass obtained, rainfall, and the season of the year (Halls, Hughes, and Peevy, 1960). Grazing should be reduced when legumes are flowering and seeding.

Game Management

No forests in eastern North America are managed for game production to the extent of longleaf pine types, and none affords more harmonious management practices for timber and game.

Wildlife enthusiasts are concerned about the effects of hardwood control on game, but chemicals and techniques now employed are inadequate for killing all of the shrubs and trees desirable for game in longleaf pine forests. Of greater concern are the vast areas of unmerchantable dense pine and hardwood stands that are without understory plants for wildlife food and protection. Where intensive site preparation over extensive areas is practiced, perhaps ⅕ to ⅓ of the area should be left in untouched strips for wildlife conservation. Ordinarily, however, as Heyward (1939) emphasized, game food is adequate as 10 to 30 percent of the longleaf pine forests are in hardwood swamps, ponds and drainages.

Birds

Quail do well on cut-over and forested longleaf pine sites. Goodrum and Reid (1954) suggest less conflict of quail with longleaf pine silviculture than with agriculture because mechanized large-scale farming, with reduced field border areas and more improved pastures, has driven quail from cultivated areas. Longleaf pine, oak, grass, legume, and shrub seeds are good quail food. On pine and pine-hardwood sites in the Southeast, one bird per 4 to 6 acres is good quail stocking. In the western part of the region, good stocking is one bird for 10 to 40 acres.

Prescribed Fire

As longleaf pine is an infrequent seed producer and seeds from shrubs are insufficient in late winter, burning is prescribed to reduce the rough and thereby encourage perennial legumes. The greater abundance of green food following fire increases vitamin A necessary for production of healthy birds.

As early as 1935, Stoddard recommended prescribed burning for improving the habitat of quail and wild turkey. The former being weak scratchers, are easily excluded from food supplies by dense tangles of wiregrass, broomsedge, or pine needles. Seeds, especially of perennial legumes like partridge pea, are smothered by mulching and unable to sprout. Also, cotton rats thrive in cover denser than that needed for quail protection, attracting partridge predators such as hawks, owls, skunks, foxes, house cats, wild cats, and snakes. Quail require for roosting, nesting, and feeding a ground cover that is open below, but which furnishes some protection from winged enemies above.

To obtain this habitat, fires are set in late winter. Burning after Japan clover and other annual legumes germinate results in their eradication. Burning as early as in January is detrimental to partridge peas, for fire-scarified seed may germinate prematurely near the warm surface of the blackened earth and be killed by later freezes. Burning after rains and at night when winds are still and the relative humidity high is recommended for initial fires in dense brush. Stoddard preferred spot fires, each "set" dying out with increasing evening dew. Spots ignited at a time which allows burning about ½ acre before dying can be set about every 100 yards.

Fires in dense brush in the second and subsequent years after the initial burn should be set later in the night as the rough, growing out of the previous years' spots of the initial fire, burns with greater intensity than 1-year cover. Fires die upon reaching the thinner cover of 1-year-old rough. Summer fires are destructive as nests and young of ground-nesting birds, as well as food and cover, are consumed.

Burning is prescribed every 3 to 4 years where fruits are dwarf varieties of blueberries or huckleberries on which turkey feed. Such shrubs are not vigorous the year of a burn, even though occasional pruning by fire is beneficial.

Grazing and Plowing

The control of ground cover density by livestock grazing is generally adverse, according to Stoddard (1935), but is recommended in lespedeza plantings by Goodrum and Reid (1954). Reid (1954) noted that less than 3 percent of an open range in Louisiana had quail food grazed by cattle.

Plowing to reduce rough; planting common and bicolor lespedezas and partridge pea under pine canopies; and fertilizing lespedeza, partridge pea, and beggars lice are suggested. Plowing and planting at ¼-mile intervals perpendicular to creeks, springs, and ponds where quail congregate encourage dispersal.

TABLE 13. ATTRIBUTES AND ADAPTABILITY FOR PLANTS COMMONLY USED ON FIREBREAKS
(after Halls, Hughes, and Peevy, 1960)

Forage plants	Palatability rating	Compatibility rating	Resistance to—		Ability to retard fire in growing season	Soil moisture condition to which species are adapted
			Drought	Flooding		
Summer grasses:						
Carpet	Good	Fair	Fair	Good	Fair	Moist
Coastal Bermuda	Excellent	Good	Excellent	Poor	Poor	Moderate-dry
Common Bermuda	Good	Good	Good	Poor	Poor	Moderate-dry
Dallis	Excellent	Excellent	Fair	Good	Good	Moist
Pangola	Good	Good	Good	Fair	Poor	Moist-dry
Pensacola Bahia	Good	Fair	Good	Good	Fair	Moist-dry
Orchard	Good	Good	Fair	Fair	Fair	Moist
Tall fescue	Fair	Good	Good	Good	Fair	Moist
Winter grasses:						
Ryegrass	Excellent	Fair	Poor	Fair	Excellent	Moderate
Oats	Excellent	Good	Fair	Poor	Excellent	Moderate
Common rye	Good	Good	Fair	Poor	Excellent	Moderate
Abruzzi rye	Good	Good	Fair	Poor	Excellent	Moderate
Summer legumes:						
Common lespedeza	Good	Good	Fair	Poor	Fair	Moderate
Kobe lespedeza	Good	Fair	Fair	Poor	Fair	Moderate
Winter legumes:						
White clover	Excellent	Excellent	Poor	Good	Excellent	Moist
Crimson clover	Excellent	Good	Poor	Poor	Excellent	Moderate
Sub-clover	Excellent	Fair	Poor	Fair	Excellent	Moist
Ladino clover	Excellent	Excellent	Fair	Good	Excellent	Moist

Deer

Deer populations in longleaf pine forests are increasing rapidly due to law enforcement and the establishment on industrial forest lands of hunting clubs with exclusive rights. Production of deer is limited by the quality of the forest range, and many techniques, such as burning, that improve cattle forage may be beneficial to deer. Lay (1957), however, noted no effect of prescribed burning upon forage quality, but understory trees and shrubs were destroyed and, with them, their mast.

About 80 woody species of browse plants are available to deer in longleaf pine forests, half of which are starvation forage. Evergreen or semi-evergreen hardwoods and vines are preferred, while pines are browsed on severely overstocked range. High choice deer foods are greenbrier, laurel-leaf, sawbrier, fringetree, white titi, big gallberry, yaupon, Virginia willow, tupelo gum, rough-leaf dogwood, rattan, black titi, strawberry bush, yellow-poplar, and sassafras (Goodrum and Reid, 1958). Greenbrier is an especially good indicator plant: where plants are small, overbrowsing has been severe.

Browsing is sometimes expressed by percent of leaves and stems consumed. Some plants tolerate 50 percent of leaves and stems browsed, others only 30 perecnt, the average being 40 percent. To make an appraisal of deer browse, list the high choice plants present and estimate the percent browsed on about 30 specimens of each high choice species. Then, if 40 percent of the tips of current season's twigs are taken on about 25 percent of the high choice browse species, overstocking is imminent. When a highly palatable plant present in significant abundance, say a frequency of occurrence of 3 percent or more, is moderately browsed, the range has reached its carrying capacity and the herd must be reduced. Where the area has a long history of deer occupancy, however, preferred plants are already depleted. Fawn production drops and carrying capacity is exceeded when about one-half of the high choice species show overbrowsing.

Woody browse drops sharply in nutrient content in winter up to 50 percent for the best forage. Nutrition, closely associated with succulence, is highest in spring. Fall and winter food, such as acorns and other mast, are generally needed; but normally there is no shortage of forage food in spring.

The maximum average carrying capacity for longleaf pine lands is estimated at 1 deer per 26 acres by Goodrum and Reid (1958).

Naval Stores

Thirty years ago longleaf pine was almost as important as slash pine in gum naval stores production, but the rapid receding of oleoresin markets to the north Florida-south Georgia areas has favored slash pine. Longleaf pine yields are about 50 barrels per "crop" of 10,000 faces more than for slash pine on identical sites, but this is rarely observed because longleaf pines usually occur on poorer sites (Schopmeyer and Larson, 1955). Longleaf pine resin is not as viscous as that of slash pine, yet response to sulfuric acid treatment is more rapid than for slash pine.

In the naval stores area, Schopmeyer and Larson (1955) believe gum naval stores operations should be included in any management plan for maximum income. Gum yields are dependent upon tree vigor and crown size: large fast growing stems with big crowns have highest yields. On poor sites, where yields from trees less than 10 inches dbh are too low to be profitable, each increase in dbh of 1 inch increases gum yields by 27 barrels per crop. Similarly, increases of 0.01 inch in average width of annual rings in the last inch of radial growth increase gum yields by 11 barrels per crop for trees with ring widths of 0.05 to 0.125 inch and with dbh between 9 and 14 inches. Each increase of 10 percent in the crown length:total height ratio improves yields by 38 barrels per crop (Schopmeyer and Larson, 1954). Longleaf pine gum yields for all sites are derived from any of the equations:

$$Y = -88.37 + 25.64d$$
$$Y = -223.2 + 25.13d + 366.7c$$
$$Y = -190.1 + 26.66d + 1163\,r$$

where Y = gum yield, per crop of 10,000 faces,
d = dbh,
$c = \frac{\text{crown length}}{\text{total height}}$ ratio,
and r = ring width (Schopmeyer and Larson, 1955).[1]

Hence, where crowns are less than 40 percent and radial growth is more than 12 rings for the last inch, the minimum diameter must be 11 inches for meeting the break-even point of 8.7 pounds of gum per year per tree. If the crown ratio is less than 40 percent and diameter growth is slower than 12 rings for the last inch, thinning from below prior to naval stores chipping is prescribed.

Gum-yield capacity is probably inherited. Production from 17-year-old progeny of above average mother trees was significantly higher than yields from progeny from a below average female parent (Mergen, 1953).

Dry face of naval stores pines occurs on longleaf. Chipping should be discontinued and the trees observed for subsequent insect and disease damage, if not promptly harvested. Interestingly, turpentining is reported to increase the proportionate volume of heartwood in longleaf pine by 5 to 10 percent (Demmon, 1936).

Prescribed Burning

Fires were often set in longleaf pine forests by aborigines to corral game, and until recent decades, it is improbable that 10 percent of the type escaped burning for periods longer than 4 years. Now, fires are prescribed for hazard reduction, brown spot needle blight control, seedbed preparation, forage improvement, and undesirable brush control. Generally fires in this type do not crown due to the open nature of the stand and the absence of heavy underbrush. Hazard reduction burns are recommended at intervals of 3 to 5 years. Fires for other purposes are discussed in appropriate sections.

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[1]Schopmeyer and Larson (1954) present gum yield tables for two site index classifications.

Effects of Fire

On Soil

Chemical Properties

Soils of the Coastal Plain supporting coniferous forests are mostly red and yellow podzolized or lateritic types developed under pine-hardwood forests. Strongly acid, they are low in available calcium, phosphorus, potassium, and nitrogen. Occasional burning may be slightly beneficial in temporarily increasing nitrogen and exchangeable cations, the ratio of nitrogen in burned and unburned soils being 1.5:1. Ash, protein, crude fat, calcium, and phosphorus are also favored by burning (Green, 1935; Heyward and Barnette, 1934). After 8 years of fire exclusion, organic matter to a depth of 6 inches in the soil was appreciably increased by a ratio of 1.6:1, possibly due to the greater growth of grass and legumes and natural decay of plant roots. For instance, the abundance of little and slender bluestems was doubled by fire exclusion (Greene, 1935).

Where soil organic matter is not destroyed by fire, bacterial growth improves. However, bacteria then hasten decay of organic matter and use nitrogen, which may have been liberated to the atmosphere by the heat of the fire, to the detriment of higher plants. Ammoniacal nitrogen generally is not released until temperature exceeds 212°F, which is rare even at the ⅛-inch soil depth. Organic matter and nitrogen were reported slightly less on unburned areas by Wahlenberg (1935, 1937), possibly because of fewer legumes than on burned areas. Production of charcoal, requiring 350°F soil temperatures that are rarely reached even in the hottest wildfires, makes organic matter resistant to decay. After burning sweetgum, yaupon, and waxmyrtle in windrows on poorly drained silt loam soils of Louisiana, height growth (of loblolly pine) was significantly greater than for unburned areas at the end of the third year: 10 vs. 5 feet. Apparently burning resulted in sustained increases in phosphorus, potassium, calcium, and magnesium for several years and soils normally acid became alkaline (Applequist, 1960) (Table 14).

TABLE 14. AVAILABLE NUTRIENTS IN THE SOIL (ppm) AND pH UNDER BURNED HARDWOOD WINDROWS AND UNBURNED AREAS WITHIN A YEAR OF BURNING
(after Applequist, 1960).

	Burned	Not burned
Phosphorus	211	7
Potassium	405	69
Calcium	5400	216
Magnesium	438	74
pH	7.5	5.5

Biological Properties

About five times as many forms of microfauna are found in the unburned ground cover of longleaf pine sites than in burned areas characterized by herbaceous cover and without F and H layers. The top 2 inches of soil have 11 times more microfauna, 93 percent of which are mites, and many more earthworms in the unburned condition (Heyward and Tissot, 1936; Heyward and Barnette, 1936).

Ants are the principal fauna, except for crayfish on poorly drained sites. As fauna makes the soil porous by forming holes and tunnels, it improves root penetration, water percolation, and soil aeration (Fig. 33). Cotton rats move from burned to unburned fields while oldfield mice and

Figure 33—Holes of small animals under litter in a longleaf forest unburned for 11 years (Heyward and Tissot, 1936; USFS photo).

Florida deer mice remain. Otherwise Arata (1959) observed no appreciable effect of burning upon mammal populations.

Briers and annual weeds increase in burned areas. Neither survival, *Cronartium* infection, nor tip moth infestation varied significantly between cleared areas and sites where hardwood slash was burned (Applequist, 1960).

Physical Properties

Frequent fires destroy the L, F, and H layers, though the latter is seldom present in measurable depth. The A1 becomes compact with massive structure and attains a volume weight as great as 1.6. Heyward (1937) described the humus of areas frequently burned as more like prairie grassland than forest.

Physical properties are generally reported to be unfavorably affected by frequent burning (Heyward, 1936; Campbell, 1955). Exclusion of fires for 7 years in southwestern Mississippi increased porousness of surface soil, raised pH as much as ½ unit, reduced spring temperatures to a depth of 3 inches by as much as 6°F, and lowered bacteria populations (Wahlenberg, 1935, 1937).

Temperatures just below the soil surface during burning reach 150 to 175°F for only 2 to 4 minutes, as the chief fuel is grass in which great drafts are only rarely created and in which heads infrequently develop. Over a 30-day period following fire slight increases in soil temperatures occur at depths of 1 inch, the average soil temperature maxima in the upper 3 inches being 5½° F higher on winter-burned than unburned areas (Greene, 1935). Fires in fuel of dropseed or rush grass, a short grass forming dense, well-aerated mats under gallberry bushes, raise soil temperatures more than in poorly aerated old roughs.

Soil moisture and texture may influence the effect upon the soil of prescribed burning. Thermal conductivity, for instance, increases with soil moisture as water is a better conductor than air; and coarse-textured soils are slightly better heat conductors than fine-textured silts and clays because less heat is transferred per unit volume (Heyward, 1938).

Infiltration may be retarded markedly at first, small dams less than 1 inch high later forming when rain water rolls over the denuded soil surface, and floating bits of organic matter or charcoal come to rest against a stationary object such as a clump of grass, a stone, or a protruding root. These minute dams discourage further surface movement of water and result in the formation of a series of small terraces on their uphill sides. Such dams and terraces occur even on coarse soils.

When burning in windrows, Bermuda and carpetgrass cover is reduced, probably releasing soil moisture for tree growth. Perhaps soil aeration is improved, as the best soil is concentrated in the burned plots due to bulldozing of surface soil with logging slash into the windrows (Applequist, 1960).

On the Forest

Seedlings

Longleaf pine seedlings are highly resistant to fire injury after their first year and until height growth begins, as the large buds are shielded from the heat by a sheath of needles. Bud protection by the rosette of needles is demonstrated by letting fire sweep over seedlings on which cigarette papers have been wrapped around buds. Needles will be burned to 1-inch stubs, leaving the papers unscorched. By this means small areas are tested for burning conditions just prior to igniting prescribed fires.

Maximum mortality occurs when stems are 1 to 1½ feet tall, while those more than 3 feet are not injured appreciably. When a Louisiana stand was burned with a hot afternoon fire having flames up to 10 feet high and averaging 3 feet, no injury occurred to grass-stage seedlings. Fifty percent of those between ½ foot and 3 feet tall were killed, but only 25 percent of those between 6 and 12 feet. No damage occurred to saplings over 20 feet tall and 2½ inches dbh (Chapman, 1947). Burning should be postponed if 250 to 500 seedlings are out of the grass until a satisfactorily stocked stand, of perhaps 700 stems per acre, is above 5 feet in height.

Survival of yearlings is closely related to ground line (root-collar) diameter. Virtually all those over 0.2 inch survive, two-thirds of those between 0.15 and 0.2 inch, one-third of those between 0.1 and 0.15 inch, and none of those under 0.05 inch (Bruce, 1951). For seedlings of any age, better survival is expected on 1-year than on older roughs, because of the greater heat intensity of accumulated fuel. Bruce reported that prescribed burning 4-year-old grass-stage longleaf pine did not affect survival. Because backfires in spring and autumn are up to 100°F hotter than headfires next to the ground in grass fuel, about 60 percent of 3-year-old seedlings 0.2 and 0.3 inch in diameter at the root collar were killed when fires were backed through a foot-deep needle and grass rough. Only half this many were killed under headfire conditions. Pine litter makes hotter fires than grass rough; therefore, seedlings under seed trees and crowns of forest walls may suffer heavy mortality. As buds of longleaf pine seedlings in sunlight may have temperatures of 110°F when the air temperature is 90°F (SEFES, 1950a), they are able to withstand only an additional 50°F rise to the 140°F lethal point. On cold days, in contrast, a rise of 100°F may not seriously injure buds.

Beyond Seedling Stage

Areas burned annually for several decades have lost 5 years' height growth due to defoliation. This is equal to a site productivity reduction from SI 80 to 75. Subsequent protection stimulates height growth significantly. Annual burning may slightly depreciate basal area growth of pole-size stands (MacKinney, 1934), but this is unlikely. In fact, understocked stands reduced by fire have an amazing ability to utilize growing space and thus approach full stocking. Chapman (1957) reported on the 40-year effects of a single summer fire on 4-year-old trees in which basal area increased from 36 at age 20 to 146 square feet per acre at age 40.

After trees are 10 feet tall, even annual burning was not found destructive. By age 33, Bruce (1947) noted only 22 cords of wood had been produced in annually burned stands though, by that time, annual growth was exceeding 2 cords per acre. Regardless of fire intensity, milacres stocked with more than 11 seedlings before burning were still stocked 6 years later. Those with 1 to 4 seedlings had greater stocking 6 years later on younger than older roughs, and more on burned than unburned sites. Severe hardwood competition caused heavy losses under all intensities of fire (Bruce and Bickford, 1950).

Fire sufficiently severe to defoliate 50 percent or more of the crown decreases stem taper of longleaf pine trees because diameter growth the following season is reduced, but not uniformly over the stem. Maximum reduction takes place at breast height and below, whereas there is little effect higher (Stone, 1944).[1] However, annual burning has resulted in

[1]A probable exception was noted by Jemison (1943) for the Southern Appalachians where, 18 years after a wildfire that scorched whole crowns, diameter growth of pines was not affected.

larger ground diameters to the extent that slightly buttressed trunks developed (Anderson and Balthis, 1944). Though not important in wood volume determinations, bark thickness has been reduced 0.05 inch by four annual fires. Tree size did not influence the amount of loss (Wahlenberg, 1936). Although the insulating facility of bark serves to protect cambium from injury, heat transfer is probably related to density, moisture content, and other properties, as well as to bark thickness (see Spalt and Reifsnyder, 1962). The time required for cambium to reach a lethal 140°F increases logarithmically with bark thickness up to about ½ inch for longleaf pine. The cambium of some hardwoods can be heated to 140°F much faster than that of southern pines, probably accounting for the greater resistance of conifers to fire injury (SEFES, 1960) (Fig. 34). (A recent study indicates the individual phloem parenchyma and cambium cells of longleaf pine are killed between 118 and 122°F (Hare, 1965).) Even if scorching is less than 16 inches high, fires burn deep depressions in bark—an indication of prolonged high temperatures at the ground line—where fuel accumulates around trees. This occurs although trees look healthy 6 months after burning (Ferguson, Gibbs, and Thatcher, 1960).

Other Effects

Longleaf pine roots are about as resistant to fire damage as aboveground parts of trees, but if the shoot:root ratio is increased by fire, they soon develop new feeders in the top few inches of soil (Heyward, 1934).

Annual burning is likely to result in pure longleaf pine forests with a few small blackjack oaks and a grass floor of pinehill bluestem grass. Unburned sites, once well-stocked with longleaf pine seedlings, will be invaded by shortleaf and loblolly pines, southern red oak, black cherry, blackgum, sweetgum, dogwood, holly, and numerous brush species, but by little grass.

Germination of seeds from fire scorched trees is poorer than from unburned stems. About 50 percent of those from the upper half of the crowns which retain green foliage are viable, 20 percent of those from scorched lower halves, and only 16 percent from trees killed by fires (Meyer, 1955).

Seedbeds

Prescribed burning is important for seedbed preparation, as suggested in 1849 by Lyell, in 1888 by Long, and in 1911 by Harper. A burned or plowed soil is the best bed, as radicals not in contact with mineral soil dry up soon after germination. Broomsedge and 2 or 3 years' accumulation of pine straw completely exclude germination. If seeds are abundant, fresh burns are probably as good as 1-year roughs, resulting in stocking which is likely to exceed 90 percent (Bruce and Bickford, 1950). Where older roughs attain good early stocking, heavy mortality accompanies summer droughts (Bruce, 1949).

Natural seedling catch due to burning, in south Alabama, equals one percent of the cost of planting, according to Morriss and Mills (1948). Burns in the late summer and autumn before seedfall (which should have been set during the previous winter) resulted in an average catch of 13,200

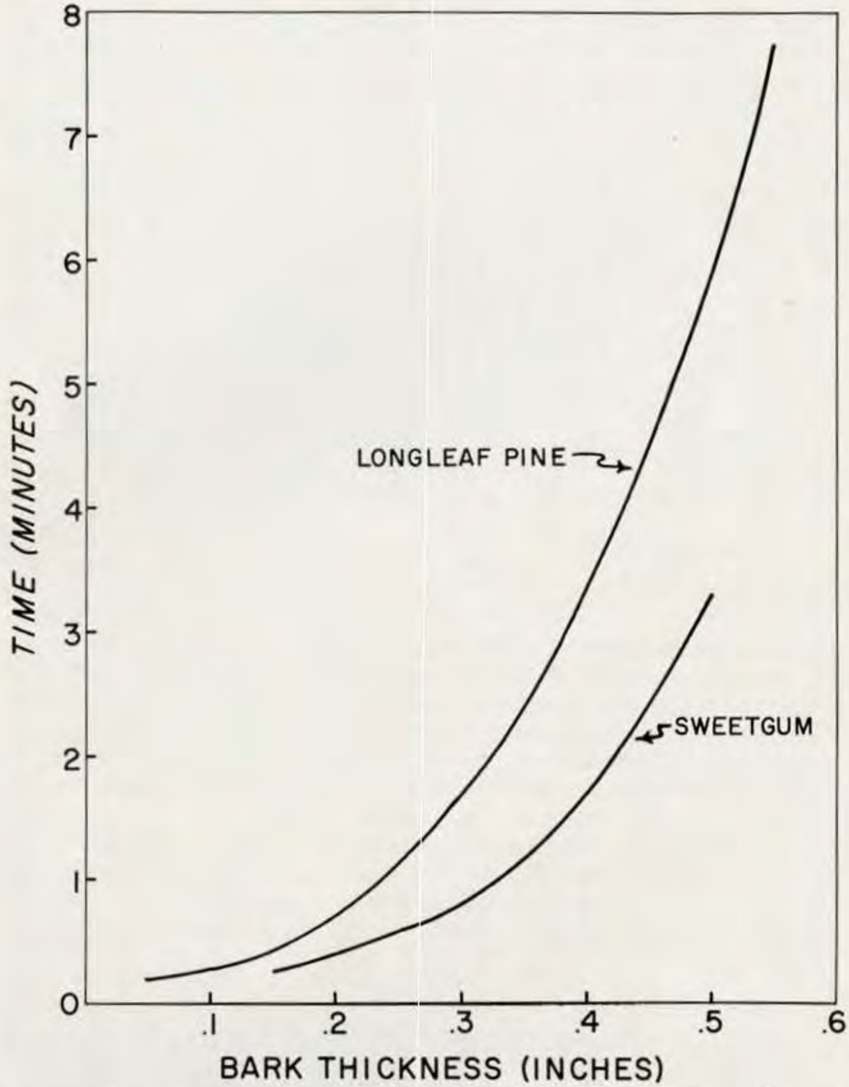

Figure 34—Time required for cambium to reach lethal temperature (140° F) upon heating of outer bark (after SEFES, 1960).

seedlings per acre. Seventy-three percent of the 26,000 acres prescribed burned had over 4,000 stems per acre, the minimum satisfactory catch. This minimum occurred only within 1½ chains of seed trees, of which there were about 2 per acre.

Stocking following burning is likely to be poor in small depressions in wet flatwoods. These wet sites, for which sundew is a reliable indicator, may be conveniently filled in by transplanting excess stock from around stand edges.

Bruce (1950) showed that the absence of competing grass roots in freshly burned areas, rather than a fertilizing or mulching effect of ashes, stimulated early growth of longleaf pine seedlings. Heavy deposits of ash, however, prohibit the penetration of radicles to soil (Gemmer, Maki, and Chapman, 1940).

Burning Techniques

Head- vs. Backfires

Backing fires consume more dead fuel than fires that run with the wind in the Coastal Plain. The reverse is true for live fuel reduction. Initial burns in heavy fuel types must be restricted to backfiring, but follow-up burns use headfires with more lasting green fuel reductions. Hough (1965) reported live vegetative regrowth, 1 year after a single winter burn, was approximately 55 percent and 70 percent of the dry weight before burning for palmetto and gallberry, respectively. Since vegetative regrowth following a single winter backfire in palmetto-gallberry fuel types is so prolific that live fuel weights and volumes may actually exceed original values within 2 or 3 years, repeat burns need to be made before the vegetative material reaches this stage. Palmetto and gallberry regrowth is retarded most effectively when reburning is possible during the first autumn following winter backfires.

In the Atlantic Coastal Plain, Hills (1957) recommends burning on the downward side of an area with checkerboard or spot fires in stands over 20 years old with 2- to 3-year roughs. Wind should be between 3 and 5 miles per hour and the temperature about 60°F. A series of fires set in lines parallel to the base line on the downwind side enables the fires to compete for space and fuel, both of which are consumed before stands are damaged. A clean burn results. In strip fires, where a solid line parallel to the base line is fired, intensity can be controlled by varying distances between lines in proportion to the amount of fuel and size and density of brush.

Flanking is good for hardwood control burns, burning faster and cleaner than a backing fire. Fires are set in the shape of a right triangle, the base of which is downwind.

Fast fires running with the wind pass too quickly to raise soil and ground level temperatures appreciably. Temperature rises rapidly as fire moves into grass-stage seedlings, is held for a few minutes, and then drops slowly. It remains high for relatively long periods of time on the leeward sides of poles and sawtimber trees in fires running with the wind, as indicated by the greater amount and the higher level of scorch on that side. Temperatures of fires burning with the wind in gallberry and matted grass are lower than when burned against the wind (Heyward, 1938) (Fig. 35).

In a 2-year-old grass rough 10 to 12 inches deep, backfires were found considerably hotter near the ground than headfires by 84 to 138°F. Just above the fuel, headfires may be warmer. Combustion apparently takes place in the fuel layer for the slower-moving fires, while for headfires it may occur at several feet above the ground where gases distilled from the surface fuel layers are oxidized (Byram and Lindenmuth, 1948). Davis and

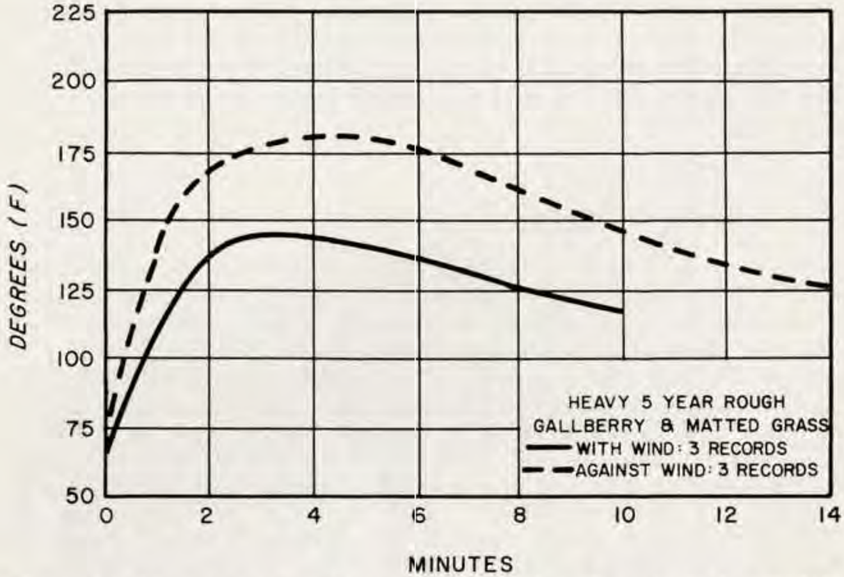

Figure 35—Temperatures of fires burning with and against the wind in gallberry bushes and grass (after Heyward, 1938).

Martin (1960) ascertained much higher temperatures with a headfire in gallberry-palmetto roughs 1 foot above the ground, but these high temperatures fell off abruptly after about 1½ minutes. Bruce (1954a) states that in grass fires, the most intense heat is ½ foot above the ground.

Season

While growing season fires frequently do serious damage, summer fires may be beneficial where it is necessary to reduce the number of seedlings to avoid stagnation. Almost half of a stand of 60,000 seedlings per acre were culled out by a summer evening (after 6 p.m., when fuel was moist) backfire of light intensity on a fine sandy loam soil in southern Mississippi. Headfires, though set in early afternoon, killed less trees (Bruce, 1951).

From July to October, only half of the work days are suitable for prescribed burns, but this is a higher percentage than in winter. Fires should be set along interior lines 40 chains apart beginning at 9 a.m. Lines back nicely until 6 p.m. and then usually can be left unmanned until morning. Summer and autumn fires should be set within 3 days of a rain of ¼ inch or more and with a steady wind of ½ to 6 miles per hour. This is slightly less than wind speeds required for winter burning, but summer winds change directions frequently and, thus, are more risky. Areas burned in August will have two-thirds of a year's rough by time of seedfall, and this may reduce stocking slightly.

For the Coastal Plain of South Carolina, Georgia, and northern Florida:

1. during the winter burning season (December through March), westerly winds are more persistent than easterly winds.

2. in early autumn (September and October), northeasterly winds are most persistent, while November is a transitional month between the early autumn and winter regimes.

3. winds in other months are much less consistent and in many areas favorable winds are so rare in the warmer months that burning is extremely difficult (SEFES, 1960).

Plant Moisture Contents

The amount of moisture in plants is directly related to the kill obtained by prescribed fires. The amount of moisture may vary, as is demonstrated with gallberry shrubs in which moisture content fluctuations are related to new leaf growth in the spring. Peak moisture contents then average 111 percent. No significant differences occur between summer, fall, and winter periods when foliar moisture is about 100 percent. Wiregrass moisture content, in contrast, averages 60 percent throughout the year and does not fluctuate significantly.

Sampling for vegetative moisture is involved because of within- and between-tree variation. The moisture content of new growth in an 8-year-old slash pine plantation on a uniform site was invariably higher than in matured tissues—60 percent for twigs and 30 percent for needles, although crown position (upper, middle, or lower) did not significantly affect the moisture content of needles. Phloem (inner bark) moisture contents for the four major southern pines ranged from 144 to 300 percent, whereas those for sweetgum and green ash averaged between 60 and 135 percent of dry weight (SEFES, 1960).

Damage Estimates

As salvage following fire cannot be delayed due to the risk of bark beetle, ambrosia beetle, and wood borer attacks, techniques for identifying trees which will probably recover have been developed. Mortality increases with increasing amounts of crown browning (expressed in percent of crown length) for all diameter classes up to 15 inches. For equal crown browning, mortality decreases linearly with increasing diameter, but with equal crown consumption, tree size has no statistically significant relation to mortality in the 4- to 12-inch dbh range (Table 15).

TABLE 15. MORTALITY BY DIAMETER CLASSES FOLLOWING A WINTER FIRE (after Storey and Merkel, 1960).

D.b.h	Longleaf	Slash	Longleaf and slash
		Percent	
4–6	28	31	30
7–9	22	28	24
10–12	21	17	21

Trees with less than 70 percent of their crowns browned seldom die if they are over 5 feet tall (McCulley, 1960; Ferguson, 1955; Storey and Merkel, 1960).

Summer fires are more damaging than winter fires, but warm weather in winter reduces resistance to injury. Winter fires often brown foliage of saw-log size trees if air temperatures exceed 45°F and fuel is abundant. Where needles are up to 50 percent consumed, severe damage may be incurred; and according to Storey and Merkel (1960), 87 percent of the trees may die where 50 to 100 percent of the needles are consumed. Because browning of all needles may not kill trees, this criterion alone is ineffective for predicting winter fire mortality. The amount of crown consumed is related to the amount of needles browned, and both are related to bud and cambium injury. Only a very tall tree could have green needles at the top and the crown consumed at its base (Fig. 36).

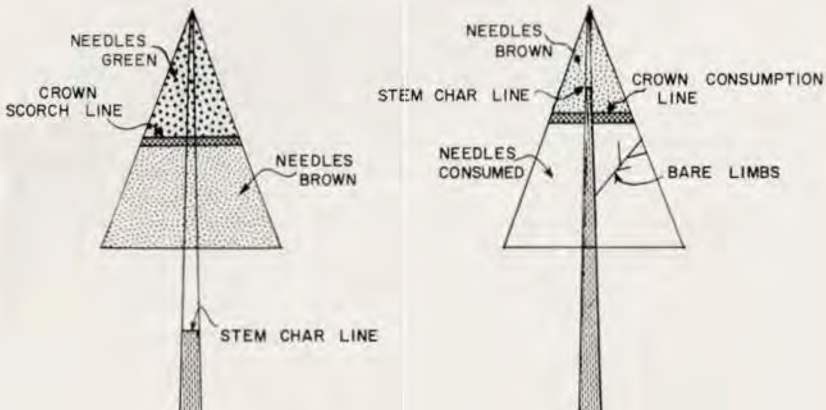

Figure 36—Types of crown and stem damage. In figure at right, the stem char line is higher than the crown consumption line. The tree on the left would live, the one on the right, in all probability, would die (from Storey and Merkel, 1960).

Storey and Merkel believe bark char more useful than crown damage for indicating risk. Char is readily discernible; independent of tree size and crown length; and is a single criterion, in contrast to needle browning and consumption (Table 16).

TABLE 16. MORTALITY BY STEM DAMAGE CLASSES (after Storey and Merkel, 1960).

Stem damage class	Longleaf	Slash	Longleaf and slash
Percent char	Percent	Percent	Percent
Heavy (81-100)	88	88	88
Medium (61-80)	53	24	39
Moderate (41-60)	9	13	11
Light (0-40)	0	0	0

Yet, crown consumption is directly related to the height of bark char, although generally not occurring to the height of the char line. Higher temperatures are required to consume green needles than to char dry pine bark.

Lethal temperature for needles, although variable, is about 140°F. Pine foliage is consumed at 350°F (Storey and Merkel, 1960). Lethal temperature, fire intensity, initial vegetation temperatures, and time of exposure to heat determine the extent of injury to trees. For instance, needles of pines (loblolly, longleaf, slash, and pitch) are killed when immersed in water at 146°F for 3 seconds. At 138 degrees, 31 seconds are necessary, and over a minute at 134°F. Nelson (1952) suggests that higher air temperatures are probably required to kill tissues and resistance to injury is greater in dry than in moist air, due to the cooling effect of transpiration.

Destructive Agents

Insects

Although wildfire, woods' hogs, and brown spot needle blight are the most destructive agents of longleaf pine, several insects are damaging. In some localities, black ants and leaf-cutting town ants destroy sprouting seeds and seedlings. Black turpentine, southern pine,[1] and Ips engraver beetles cause serious damage. The Nantucket pine tip moth[1] does not attack longleaf pine; the resistance of slash and longleaf pines to attack by tip moths may be related to the inability of the larvae to bring about a rapid crystallization of the oleoresins of these species (Yates, 1962). Crickets clip juvenile needles near the ground line, but seedlings are seldom killed (Russell, 1958).

Disease

Fusiform canker caused by *Cronartium fusiforme* is negligible on longleaf pine, although rapid growth and localized high humidity may contribute to occasional high infection, most of which occurs during the first 7 years and in open stands. The canker associated with *Atropellis tingens*, principally on branches, is also of negligible importance, probably because the long needle sheath excludes excessive water at the point of infection, in contrast to the sheath of the susceptible slash pine (Diller, 1943). Pitch canker, caused by *Fusarium lateritium* f. *pini*, may kill stems smaller than 5 inches dbh, although larger trees are seldom girdled (Berry and Hepting, 1959). The needle cast fungi *Hypoderma hedgcockii* and *Hophodermium pinestri* attack longleaf pines. Root rot caused by *Fomes annosus* is of increasing concern.

Brown Spot Needle Blight

Brown spot needle blight, caused by *Scirrhia acicola*, reduces grass-stage seedling growth. Control is necessary as infected trees otherwise remain in the grass-stage for periods exceeding 10 years, and many die.

[1]These insects and their control are discussed in *Silviculture of Shortleaf Pine* (this series).

While the disease occurs wherever longleaf pines grow, its frequency is as much as 20 times greater on unburned than on burned sites (Siggers, 1934). It is less serious on the Atlantic Coastal Plain than further west (Siggers, 1934), and its occurrence on seedlings in the South Carolina Fall Line is attributed solely to nursery stock inoculation. Chapman (1948) reported the disease rare prior to 1913. The amount of disease is influenced by climate, seedling density, shading of foliage, height of foliage above ground, and season of the year. The presence of an overstory may inhibit the development of the disease (Boyer, 1963).

Straw-yellow spots form on needles at first, and these later change to light brown, often with darker brown borders or, after cool weather sets in, dark purple borders. Spots ⅛ inch long run together to form oblong areas of diseased tissue. After needles die, the diseased areas are embossed above the level of the remainder of the needle. Three successive annual defoliations are usually necessary to kill seedlings (Derr, 1957). Defoliation does not occur nor is growth retarded after conical buds appear and the main axis elongates. Increasing immunity with growth may be due to the greater height to which rain splash must carry infecting spores, rather than to the physiology or morphology within the plant.

Sexual ascospores of *S. acicola*, which mature within 2 to 3 months after infected needle tissues die, are wind-borne and spread the infection great distances at all seasons of the year. Asexual spores, the conidia, are exuded in gelatinous masses that are washed or splashed by rain, causing infection near tips of young elongating needles in the spring. Conidia on needles at higher levels are washed to lower needles and passed into the soil when needles are dropped. Secondary conidial infections are produced by May and needles begin to die in June (Lightle, 1960).

Webster (1930) observed that badly diseased trees from a nursery were planted with good success. Perhaps the needle tissue killed by the disease reduced transpiration and therefore permitted good survival. There is evidence, yet unproven, of disease-resistant strains (Lightle, 1960).

Damage Estimation

In estimating damage, the needles already killed must be included. These may remain in place, supported by surrounding vegetation, but sometimes fall off the stem. Siggers (1934) sampled for an estimate 100 seedlings which had started height growth sufficiently to lift foliage above surrounding grass, as these seedlings usually suffer the greatest proportionate amount of infection. Since season of defoliation affects growth —November worst, February least—estimates of brown spot need to take into account how long needles have been dead as well as the proportion dead. Premature shedding, color, needle shape distortion, and brittleness of dead tissue aids judgment.

In the absence of disease or fire, longleaf pine seedlings retain needles for a minimum of 17 months—from April to August. Foliage in the second season may be partially shed and occasionally entirely gone by the end of November.

Control

Chemical

Bordeaux mixture (4 pounds copper sulfate, 4 pounds hydrated lime, and 50 gallons of water) and Ferbam are effective fungicides. Spreader-stickers, such as calcium caseinate or raw linseed oil, should be added to the solution. One or two sprays during each of the first 2 years after seed germination or planting enable undelayed height growth initiation, but control is not complete. Derr (1957) recommends additional treat-

Figure 37—Untreated (row with ax handle) and Bordeaux-treated (on either side) longleaf pine seedlings infected with brown spot needle blight (Derr, 1957; USFS photo).

ments in the third and fourth years (Figs. 37 and 38). Needles should be thoroughly wetted at each treatment. Four-year-old Bordeaux-treated trees were 11 feet tall and untreated ones only 2 feet tall (Siggers, 1934).

Fire

In Louisiana, fire exclusion increased brown spot needle blight to such an extent that seedling stands were wiped out; and where sanitation burning was delayed, trees were 10 years longer producing sawlogs (Chapman, 1943). However, there is a paradox on burning grass-stage seedlings:

Figure 38—While in the grass-stage, these trees were sprayed with Bordeaux to control brown spot needle blight. Now, at age 7, they are nearly 10 feet tall (Derr, 1957; USFS photo).

as the pathogen is spread from soil to seedlings by rain-splash, keeping the soil covered through fire exclusion is desirable. Yet the disease is best controlled by prescribed burning to eliminate blighted needles and provide for new, disease-free foliage.

Fires should be prescribed only when infection has caused death to more than one-third of the foliage by late November or December. If many seedlings have begun elongation, burning is not necessary. However, trees less than 6 inches tall with severe infection may tolerate up to two-thirds defoliation without much more mortality from burning than from the fungus alone. If defoliation exceeds one-third on seedlings 6 to 18 inches tall, burning has been delayed too long and fire-killed seedlings will number more than those killed by brown spot. All seedlings completely defoliated by disease are likely to die when burned, as buds are not protected. Without regard to height, each 10 percent increase in brown spot on needles increases mortality from fire by 5 percent (Bruce, 1954a).

Burning should be done in January or February. Postponement for a year or more may delay height growth and increase subsequent mortality from the disease and from the prescribed fire, as dead needles feed and intensify the flames.

A single fire among heavily infected seedlings that have not started height growth reduces the disease the first year and permits retention of foliage through the following season. Needle retention is necessary, assuming height growth before development of spring foliage depends on food accumulated during the preceding season. Marked stimulation of height growth results from retention of needles through the second season and should not be looked for until spring of the third season following a fire. Therefore, burning is prescribed no more frequently than at 3-year intervals, although Chapman (1948) recommended it in the third and fifth years. It may be necessary to prescribe burn the winter before height growth starts and then keep fire out until the crop is beyond the zone of brown spot defoliation.

The effect of a single fire on disease control nearly always disappears by the fourth season and some reinfection occurs the year after burning. Areas to be burned should be larger than 30 to 40 acres for efficient brown spot control (Bruce and Bickford, 1950).

It should be recognized that burning may have an adverse genetic effect. If a heritable factor for brown spot resistance or early height growth is present, seedlings carrying this factor would tend to be in early height growth when the rest of the seedlings are in the grass stage and in need of a control burn. Thus burning would tend to eliminate the genetically superior seedlings (Verrall, 1962).

Examples

A plantation on fine sandy loam was 37 percent killed by brown spot 3 years after planting, at which time the principal cover was weeds and *Andropogon* grasses. Fires were prescribed then, and again at age 6, for late afternoon and evening in the direction of a steady 1- to 2-mph wind. At age 11, burned areas had twice as many seedlings out of the grass, three-fourths were 1½ feet tall and thus above the brown spot danger level, and two-thirds were breast high in contrast to 22 percent for the untreated sites (Wakeley and Muntz, 1947; Muntz, 1947).

A late afternoon winter fire, running with the wind when relative humidity was 32 percent, temperature about 50°F, and 3 days after a ½-inch rain, most severely affected seedlings 6 to 18 inches tall and those with most defoliation (Fig. 39). Seedlings less than two-thirds defoliated by brown spot were not injured appreciably more than healthy trees (Bruce, 1954a).

Rodents

Pocket Gophers

Pocket gophers, soil burrowing vegetarian rodents appearing like stout mice, but with strong claws for digging, are particularly obnoxious in longleaf pine grass-stage seedling stands in sandy soils of the Gulf States. Making extensive soil tunnels about 4 inches in diameter in their search for starch and the resinous flavor in pine roots, pocket gophers may destroy, by severing tap roots, 50 percent of the seedlings in natural and planted well-stocked stands. As the animals are meadow dwellers, preferring bitter dandelion roots to pine, they leave young forests when

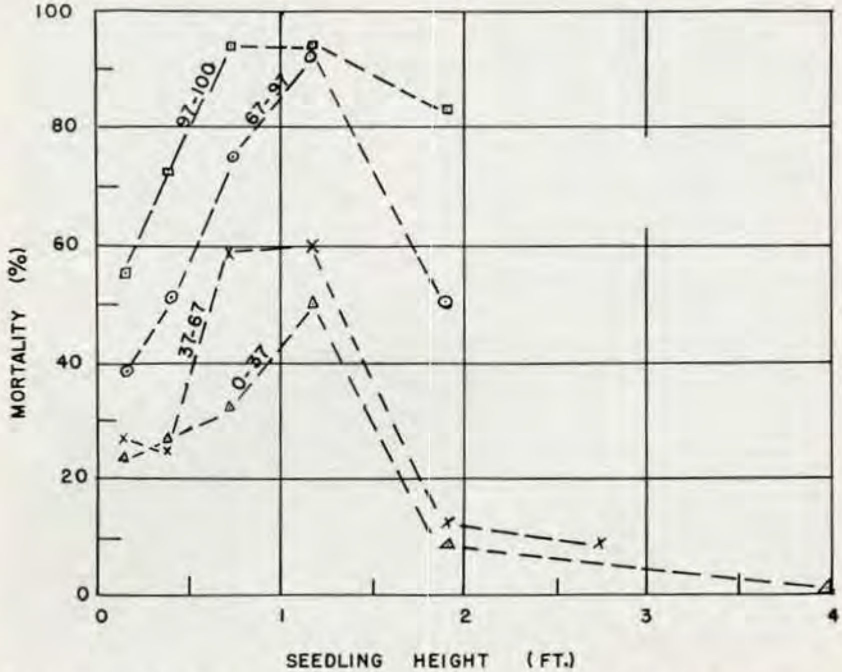

Figure 39—Effect of seedling height and brown spot defoliation on mortality of longleaf pine seedlings 18 months after a winter fire. Numbers on lines represent percentages of needles infected (from Bruce, 1954a).

crowns close. It is an unfounded opinion that pine roots are not edible to pocket gophers, but are cut if they obstruct tunneling (Dingle, 1956).

Tunnel entrances are usually quite obvious, perhaps a foot wide, and made at a rate of about 2 a day after summer rains. A family has been known to "throw out" over 300 on 1½ acres in a single year (Mohr and Mohr, 1936).

Arsenic bait placed in tunnels is used and strychnine shows promise. Treated diced carrots are placed in the main tunnel in a hole first made with a probe or soil auger. The hole is then covered at ground level to prevent entrance of light and air into the tunnel (Fig. 40). This control treatment requires 4 to 8 man-hours per acre.

A mechanical bait applicator that can be locally fabricated is described by Kepner and Howard (1960). For quick once-over operation, the tractor-pulled, plow-like implement with a shank on a slender shaft makes an artificial burrow at 7 to 11 inches below the soil surface and meters poison grain into the burrow. Burrows are made in moist, but not sticky, reasonably firm soil—when plowing conditions are good—every 15 to 30 feet, thus intercepting natural tunnels. Little disturbance occurs to the surface soil. Pocket gophers have access to the bait and because of the animal's aggressiveness and curiosity are prompted

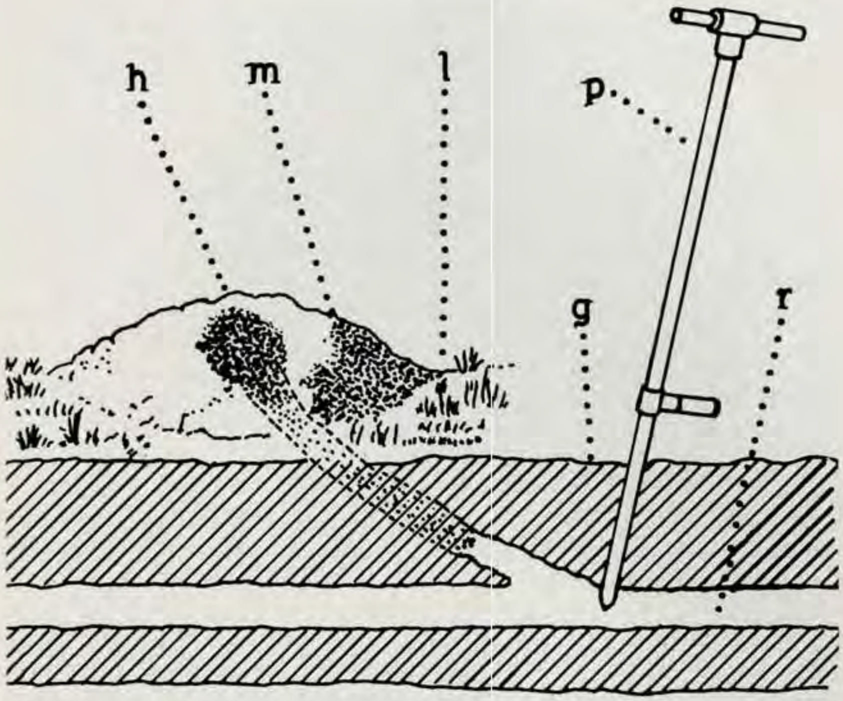

Figure 40—Method of baiting gopher tunnels with strychnine-treated root bait. Terminus (h) of lateral (l) in mound (m). Probe (p) is used to find the main tunnel (r) and to make a hole (g) for inserting bait. The hole is then covered at ground level to prevent entrance of light and air into tunnels (from Dingle, 1956).

to investigate the new tunnel. Six to 7 hours per acre are required, using 1¼ pounds of bait per 1000 feet which ordinarily reduces the population by 50 to 75 percent.[1]

Squirrels

In south Georgia, longleaf pine seed are rapidly consumed by squirrels (Halls, Burton, and Southwell, 1957). Control, other than hunting, is usually not practiced.

Rabbits

Cottontail rabbits destroy longleaf pine plantations by biting off seedling tops. Losses are greatest the winter of planting. Several repellents are available:

1. Zinc dithiocarbamate—To prepare the zinc carbamate, add 5 gallons of commercial preparation (ZIP) to (a) 24 gallons of wax emulsion

[1]See Howard and Ingles (1951) on trapping these rodents for ecological studies.

plus 71 gallons of water, or (b) 120 pounds of asphalt emulsion (paste) plus 85 gallons of water, or (c) 6 gallons of latex emulsion plus 89 gallons of water. Seedlings are sprayed in the nursery bed just before lifting.

2. Lime sulfur (calcium polysulfide)—This is prepared by adding 11 gallons of 30 percent calcium polysulfide to a mixture of 120 pounds of asphalt emulsion and 75 gallons of water (Burns, 1960). One hundred gallons of mixture, applied during the dormant season, treats 300,000 to 400,000 nursery bed seedlings. Browsing of out-planted stock is reduced by one-half.

3. Copper carbonate—Three pounds of asphalt emulsion are mixed with 2 quarts of water, this mixture added to 2 pounds of copper carbonate, and the whole diluted with 8 quarts of water. Seedling tops can be dipped before planting or the chemical sprayed on foliage after planting. It is toxic if applied to roots (Mann and Derr, 1954).

Rats and Mice

Cotton rats are locally serious pests, as in central Louisiana in direct-seeded longleaf pine stands still in the grass-stage. The rat is 10 to 12 inches long with a buff and black back, white belly, stubby tail, and ears hidden in fur.

Trees less than $\frac{1}{3}$ inch in diameter at the root collar are bitten off at or below the ground line; larger ones are girdled for $\frac{1}{3}$ to $\frac{1}{2}$ the circumference and show narrow tooth marks. Partially girdled trees may show no damage, while girdled stems may appear as though infected with brown spot needle blight. Average kill is about 10 percent. No attacks have been noted for the Sonderegger hybrid of loblolly and longleaf pines (although loblolly pines less than 2 feet tall have been attacked). Rats are most abundant where fire and cattle are excluded and a heavy rough of bluestem grass has developed in which narrow runways are made. Pale greenish-yellow droppings and small piles of shredded grass are left in the runways. Brush piles from hardwood control operations also are a favorable habitat.

Periodic inspections are recommended for areas subject to attack, especially when rough and brush are heavy. Burning during the winter of discovery, followed by trapping in summer with poisoned baits provides control. Conventional rodent poisons are camouflaged with peanut butter, pine seeds, apples, and carrots (Meanley and Blair, 1955).

Pine mice occur in unburned soils within $1\frac{1}{2}$ inches of the surface. They construct a labyrinth of holes and tunnels $\frac{3}{4}$ to 1 inch in diameter. Where damage is excessive, control is the same as for cotton rats.

Weather

Ice

At Athens, Georgia, in the Piedmont and beyond the natural range of longleaf pine, one-fourth of the stems in sapling-size stands were destroyed by an ice storm. The long, dense foliage accumulates a heavier load than the needles of other conifers. Breakage occurs at a point where stems are about 2 inches in diameter. Slightly bent trees straighten, and many bent severely make partial recovery (McKellar, 1942).

Hail

Hail also is injurious to longleaf pine. Trees are defoliated and bark is broken and cut on stems as large as 5 inches dbh. Resin deposits mark the original scars and callus layers of new wood constitute minor defect. Diameter growth is retarded due to defoliation. Evidence of injury appears for 4 years after the storm (Stone and Smith, 1941).

Wind

Clays at shallow depths are indicative of sites susceptible to windfall. Following heavy rains and hurricane winds in south Alabama, Croker (1958) counted over 90 percent of the trees windthrown in soils with less than 2 feet to clay. Windthrow is encouraged by restricted root development and water saturation. Soils with clay or sandy clay within 2 feet of the surface should be scouted for windthrown trees following Gulf Coast storms, as salvage avoids the spread of insects.

Nutrition

Deficiency Symptoms

The nutrition of longleaf pine seedlings has long been philosophized upon, but little experimental evidence is presented. Pessin, in 1937, grew seedlings in pots to determine deficiency symptoms, as follows:

Full nutrient solutions	fascicles with 3 needles, healthy green color, vigorous.
Minus phosphorus	healthy green color, 2-needle fasciles.
Minus calcium	pale green, spindly seedlings, some needles brown at tips.
Minus sulphur	healthy green color, thin and spindly needles.
Minus nitrogen	pale green, delicate needles, less needles than in other treatments except minus potassium and minus iron, needles brown from tips to middle.
Minus magnesium	pale green to yellowish needles, brown needle tips.
Minus potassium	fascicled needles bluish-green except at tips, which are dark brown to black, but most needles single (primary phase), bluish green, short, stout, and without brown tips.
Minus iron	pale yellow to white, weak, spindly foliage.

Growth

Poorest growth in Pessin's (1937) study was in potassium- and iron-deficient cultures, but best growth occurred in phosphorus-deficient as well as in complete nutrient solution pots. As longleaf pine occurs naturally in soils low in available phosphorus, it is assumed that the species demands little of this element. Requirements for nitrogen, calcium, and sulphur are also probably low. From Pessin's pots, it appears that magnesium, iron, and potassium requirements are not appreciably below those of many agricultural crops. Bateman and Roark (1953, 1957), in Louisiana, and Paul and Marts (1931), in deep sands in Florida, obtained increased longleaf pine growth with complete fertilizer applications. In the latter study, up to 19,000 pounds per acre (270 pounds per tree) of sodium nitrate and ammonium sulphate, plus 245 pounds of super-phosphate and 190 pounds of potassium sulphate per tree were applied over a 3-year period to trees ranging in age from 100 to 250 years. Water, however, was the most important factor in latewood development. Nitrate fertilizer further stimulated latewood growth, while radial growth was increased with complete fertilizer. Needles were longer, darker, and more persistent when trees received complete fertilizer. Weight of potted plants in south Mississippi soils receiving complete fertilizers averaged twice those given nitrogen applications and those given none (Allen and Maki, 1955). Pessin (1944) reported no growth response from fertilization of longleaf seedlings in south Mississippi with 400 pounds per acre of ammonium sulphate.

Flowering and Cone Production

Cone production for longleaf pines in Florida was greatly stimulated by complete fertilization and irrigation over a 5-year period (Gemmer, 1932). Some increased cone production through application of complete fertilizers (5-15-5) was also obtained by Allen (1953) in Alabama and Mississippi. Fertilized in February for 2 years, 8-inch trees received 19 pounds of fertilizer per application, 10-inch stems 30 pounds, and 12-inch trees 44 pounds. Although significant differences were found, relatively few cones were involved.

Survival

A significant decrease in survival of planted longleaf seedlings due to fertilization with 100 pounds per acre of complete (6-18-5) fertilizer was reported in Louisiana (Derr, 1957). The detrimental effect of the fertilizer, poured into the closing slits, was attributed to increased competition of weeds and grasses stimulated by the treatment.

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APPENDIX

Common and scientific names of species mentioned in the text.

Trees

Ash, Green	*Fraxinus pennsylvanica*
Blackgum	*Nyssa sylvatica*
Cherry, Black	*Prunus serotina*
Dogwood, Flowering	*Cornus florida*
Roughleaf	*drummondii*
Fringetree	*Chionanthus virginicus*
Hickory	*Carya* spp.
Holly	*Ilex* spp.
Mulberry, Red	*Morus rubra*
Oak, Blackjack	*Quercus marilandica*
Bluejack	*incana*
Laurel	*laurifolia*
Northern Red	*rubra*
Post	*stellata*
Scarlet	*coccinea*
Southern Red	*falcata*
Turkey	*laevis*
Water	*nigra*
White	*alba*
Pine, Loblolly	*Pinus taeda*
Longleaf	*palustris*
Pitch	*rigida*
Pond	*serotina*
Sand	*clausa*
Shortleaf	*echinata*
Slash	*elliottii*
Sonderegger	*sondereggeri*
Sassafras	*Sassafras albidum*
Saw-Palmetto	*Serenoa repens*
Sweetbay	*Magnolia virginiana*
Sweetgum	*Liquidambar styraciflua*
Tupelo Gum	*Nyssa aquatica*
Willow, Virginia	*Itea virginica*
Yaupon	*Ilex vomitoria*
Yellow-Poplar	*Liriodendron tulipifera*

Shrubs

Blueberry	*Vaccinium* subgen. *Euvaccinium*
Gallberry, Big	*Ilex coriacea*
Bitter	*glabra*
Gopher-Apple	*Geobalanus* spp.
Greenbrier	*Smilax* spp.
Huckleberry, Dwarf	*Gaylussacia dumosa*
Laurel-Leaf	*Smilax laurifolia*

Muscadine	*Vitis* spp.
Myrtle	*Myrica* spp.
Rattan	*Berchemia scandens*
Sawbrier	*Smilax bona-nox*
Strawberry-Bush	*Euonymus americanus*
Summersweet Clethra	*Clethra alnifolia*
Sweetfern	*Comptonia peregrina*
Titi, Black	*Cliftonia monophylla*
White	*Cyrilla racemiflora*
Viburnum	*Viburnum* spp.
Waxmyrtle	*Myrica cerifera*

Herbs and Vines

Big Trefoil	*Lotus uliginosus*
Bitterweed	*Helenium tenuifolia*
Clover, Crimson	*Trifolium incarnatum*
Japan	*Lespedeza striata*
White	*Trifolium repens*
Dandelion, False	*Sitilias caroliniana*
Dogfennel	*Anthemis cotula*
Goldenrod	*Solidago altissima*
Ladino-Clover	*Trifolium* spp.
Lespedeza, (Kobe)	*Lespedeza striata*
Pea, Partridge	*Cassia fasciculata*
Rue, Goats'	*Tephrosia virginiana*
Sundew	*Drosera bevifolia*
Sunflower, Swamp	*Helianthus augustifolius*
Weed, Beggar	*Desmodium* spp.
Yankeeweed	*Eupatorium compositifolium*

Grasses

Beardgrass	*Andropogon glomeratus*
Bluestem, Big	*Andropogon furcatus*
Little	*scoparius*
Pinehill	spp.
Slender	*tener*
Broomsedge	*Andropogon virginicus*
Carpetgrass	*Axonopus affinis*
Curtis Dropseed	*Sporobolus curtissii*
Dallisgrass	*Paspalum dilatatum*
Deergrass	*Rhexia* spp.
Grass, Bahia	*Paspalum notatum*
Coastal Bermuda	*Cynodon dactylon*
Common Bermuda	*dactylon*
Orchard	*Dactylis glomerata*
Pangola	*Digitaria decumbens*
Panicum	*Panicum* spp.
Rush	*Sporobolus* spp.
Tall Fescue	*Festuca elatior* var. *arundinacea*
Toothache	*Ctenium aromaticum*

Indiangrass, Lopside	*Sorghastrum* spp.
Muhly, Cutover	*Muhlenbergia expansa*
Oats	*Avena* spp.
Panicums	*Panicum* spp.
Paspalum	*Paspalum* spp.
Rye, Abruzzi	*Secale cereale* var. *abruzzes*
Common	*cereale*
Ryegrass	*Lolium multiflorum*
Switchgrass	*Panicum virgatum*
Three-Awn, Pineland	*Aristida stricta*
Trinius	spp.
Wiregrass	*Andropogon scoparius*

Mammals

Cat, Wild	*Lynx rufus*
Deer, White-Tailed	*Odocoileus virginianus*
Fox, Gray	*Urocyon cinereoargenteus*
Red	*Vulpes fulva*
Gopher, Pocket	*Geomys* spp. and *Crategeomys* spp.
Mice, Deer and Oldfield	*Peromyscus* spp.
Pine	*Pitymys* spp.
Rabbit, Cottontail	*Sylvilagus floridanus*
Rat, Cotton	*Sigmodon* spp.
Skunk	*Mephitis* spp.
Squirrel	*Sciurus* spp.

Birds

Blackbird, Brewers	*Euphagus cyanocephalus*
Redwinged	*Agelaius pheniceus phoeniceus*
Rusty	*Euphagus carolinus*
Cowbird	*Molothrus ater ater*
Dove, Mourning	*Zenaidura macroura carolinensis*
Juncos	*Junco hyemalis hyemalis*
Meadowlark	*Sturnella magna magna*
Quail, Bobwhite	*Colinus virginianus virginianus*
Sparrow, Savannah	*Passerculus sandwichensis savanna*
Vesper	*Pooecetes gramineus gramineus*
Turkey, Wild	*Meleagris gallopavo silvestris*

Insects

Ant, Black	*Componotus castaneus*
Texas Leaf-Cutting	*Atta texana*
Beetle, Ambrosia	*Monarthrum* spp.
Black Turpentine	*Dendroctonus terebrans*
Pine Engraver Bark	*Ips* spp.
Southern Pine	*Dendroctonus frontalis*
Cricket	*Anurgryllus muticus*
Mite	*Paratetranychus* spp.
Moth, Nantucket Pine Tip	*Rhyacionia frustrana*
Webworm, Pine	*Tetralopha robustella*

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