1961

Flooding and Drainage Effects on Slash Pine Loblolly Pine Seedlings

Laurence C. Walker
Stephen F. Austin State University

J.M. Daniels

R.L. Daniels

Flooding and Drainage Effects on Slash Pine and Loblolly Pine Seedlings

BY
LAURENCE C. WALKER
R. LAMAR GREEN
JOE M. DANIELS

SLASH PINE (*Pinus elliottii* var. *elliottii* Engelm.) and loblolly pine (*P. taeda* L.) seedlings appear to have a high degree of tolerance to poor drainage and flooding. This tolerance is important in the silviculture of the southeastern Coastal Plain flatwoods where imperfectly drained Bladen clay loam and related soils predominate. Approximately 75 percent of the area in these soils, in which both surface and internal drainage are poor, is devoted to woodlands. Pines are the most valuable species, yielding high quality timber, pulpwood, and naval stores. Generally, the pines are restricted to the better drained sites while less valuable hardwoods are the dominant species in low-lying, poorly drained zones. Throughout this region, extensive areas occur in which, when drained, stands of pine develop from natural seedfall. Both stocking and growth of pines may be substantially increased by providing adequate drainage.

Trousdell and Hoover (1955) are mindful that "in years with heavy spring rainfall, it may be difficult to regenerate pine stands on some poorly drained sites by clearcutting systems because of standing water on the prospective seedbed during the germination period." Wet conditions also result in death of residual seed trees.

In addition to silvicultural implications, high water causes costly and unpredictable logging operations. Heavy machinery makes logging roads impassable, and the puddling of soil by compaction reduces productivity of a site.

No major research has been directed at determining effective and economical drainage coefficients for woodlands and, therefore, the full benefit of particular water removal rates to both tree growth and logging remain speculative. Agricultural and civil engineers requested to design woodland drainage systems have little data on which such designs may be based. Nevertheless, there is much active interest in woodland drainage and engineers are receiving an increasing number of requests for assistance in the layout of water-removal systems.

This paper presents the results of an effort to determine the effect of (1) continuous flooding, (2) continuous drainage,

---

L. C. Walker is Associate Professor, School of Forestry, University of Georgia; R. L. Green, now head of the Department of Agricultural Engineering, University of Maryland, was Superintendent of the Southeastern Tidewater Experiment Station at Fleming, Georgia, during the course of this study. J. M. Daniels is an engineering aid at the station. Journal Series No. 119 of the College Experiment Station of the University of Georgia College of Agriculture Experiment Stations. The study, a cooperative project of the University and the Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Dept. Agric., was supported in part by the Georgia Forest Research Council. Manuscript received Jan. 20, 1960.

and (3) three drainage coefficients upon survival and growth of slash and loblolly pine seedlings. A drainage coefficient is the amount of water, in inches, removed from a site during a 24-hour period.

Literature Review

The effect of deep channel drainage on slash and loblolly pines in the North Carolina coastal area, where ditching lowered water tables to a distance as great as 1000 feet, has been reported by Pruitt (1947) and Schlaudt (1955). Height growth was increased from the ditch to a distance of 500 feet, and soil physical properties were improved. The slightly detrimental growth effect of flooding upon shortleaf (*Pinus echinata* Mill.), loblolly and pond pines (P. *serotina* Michx.) is reported by Hunt (1951). Although loblolly and shortleaf pines made more growth than pond pine in sand cultures flooded for various periods, in general, all seedlings proved unusually resistant to injury. After 12 weeks, slightly reduced growth was recorded for seedlings continuously flooded with standing water. Flooding for three months did not permanently damage root systems; but after ten months, the roots appeared so badly injured that the plants would probably have died if the soil dried below field capacity. Gaiser[1] also reported loblolly pine to be more resistant than pond pine to flooding injury. Both species made better growth in soil intermittently flooded for short periods, 2 days out of 9, than in soil maintained at field capacity.

Prompt removal of excess water from small stagnant bogs beneficially influenced leader growth of black spruce *Picea mariana* (Mill.) B.S.P. and balsam fir (*Abies balsamea* L. Mill.) saplings. Acceleration of growth decreased with distance from the drainage ditch in this Michigan study (Satterlund and Graham 1957).

The effect of flooding on seedling survival is exhibited even for such hydrophytes as baldcypress, *Taxodium distichum* (L.) Rich. Ten to 12 days submergence may cause death. Demaree (1932) observed that this species must grow to sufficient height during the first year to stay above floods during the second year except for a very few days at a time.

Other species detrimentally affected by high water include red pine (*Pinus resinosa* Ait.) (Stone *et al.* 1954), conifers of the Lake States' region (Ahlgren and Hansen 1957), and numerous hardwoods in the upper Mississippi River (Green 1947, Yeager 1949) and adjacent to northern Swiss lakes (Kuster 1948). Ahlgren and Hansen's work showed no uniformity in the effect of duration of submergence on subsequent terminal growth. Trees flooded for less than 28 days in many cases showed as much growth reduction as trees flooded for longer periods.

Redox potential measurements show that conditions favoring oxidation and/or reduction in a soil in the absence of oxygen are not readily removed by additions of oxygen deficiency were considered to be waterlogging on plant growth may persist for some time after the soil is drained, and even temporary flooding may be injurious to plant growth (Scott and Evans 1955).

The variation among species in ability to withstand flooding is, of course, ancient knowledge, but the mechanics of continued growth are speculative. Kramer (1949) and Leyton and Rousseau (1958) note that *Salix* roots, for instance, grow and absorb water in almost complete absence of oxygen. *Heliotropium*, on the other hand, ceased water absorption 15 hours after the soil atmosphere was replaced by nitrogen. Carbon dioxide toxicity and oxygen deficiency, were considered to be the causes. Reduced water absorption might be due to lessened metabolic activity of roots or physical changes in permeability. It is accompanied by retarded transpiration, photosynthesis, and mineral absorption, and finally manifested as wilting. Kozlowski (1958) and Bergman (1920) reported that in flooded soils, absorption of water by roots often decreased and lagged

[1]Gaiser, R. N. Unpublished thesis. Duke University, 1947.

behind transpiration, causing leaves to dry out.

Further evidence that absorption is not the only factor inducing injury was presented by Kramer (1933) to the effect that loblolly pine seedlings absorbed water and appeared uninjured for two weeks after roots were killed. As Kramer later stated (1951), lack of water cannot explain the curvature of leaf tips, hypertrophy, nor development of adventitious roots. These changes take place more likely in turgid, growing tissues. He suggested that flooding injury may be related to disturbance of translocation of carbohydrates and possibly of hormones. Interference with downward translocation due to lack of oxygen "results in an accumulation of carbohydrates in the lower part of the stem, near the water line, causing hypertrophy and the development of adventitious roots." Kramer considers it unlikely that nutrient deficiencies are an important factor in flooding injury but, rather, he suggests that poisoning by toxic substances moving up from dying roots may be the reason. Loblolly pine transpiration, according to Parker (1950), increased to 125 percent of the expected rate for a week after flooding, then decreased constantly to 60 percent when drained 4 weeks after flooding, then a week later to 20 percent.

Water-logged soils high in organic matter, typical of many southeastern coastal forest sites, may also contain toxic quantities of iron, sulphides, and manganese, built up as a result of the presence of CO_2 released in biological activity (Kramer, 1949). Chlorosis and wilt of leaves of flooded plants is known to decrease with removal of CO_2 from soil solutions (Jackson, 1956).

Dean (1933) found aeration important in the production of root hairs and lateral roots, even for aquatic plants. In studying hydrophytes, Bergman (1920) reported that as soon as the plants growing beneath the surface of swamp water showed signs of wilting, supplying air or oxygen would result in restoration to normal.[2]

Description of the Site

The study was conducted at the Southeastern Tidewater Experiment Station, south of Savannah, Georgia. The natural forests of the area, known as the flatwoods, are principally loblolly pine, intermingled with willow oak, longleaf pine, sweetgum, and reeds.

The Bladen clay loam of the area is a low humic gley soil formed from thick beds of acid clay. It is noted for its slow internal drainage and plastic *B* horizon. The principal type of the series is fine sandy loam with slightly lighter color of the *A* horizon than the yellow-brown mottling typical of the underlying *B*. The *A* horizon is 4 to 10 inches thick and strongly acid. The texture of the *B* horizon varies from sandy clay to clay. When dry, it is extremely hard, shrinks and cracks, and breaks into angular blocks. The *B* horizon is about 6 feet deep in the study area. Bladen soils join areas of tidal marsh and occur on broad level flats with a few areas in ponded positions from 4 to 30 feet above sea level. Drainage canals are considered essential for agriculture. The impermeability of Bladen soil is indicated by the very slight lowering of the water table at stand edges in contrast to the sharp decline one-half chain within a stand (Trousdell and Hoover 1955).

Studies with replicated lines of drawdown wells, about 500 yards from the area of the experiment reported here, showed that a drainage ditch five feet deep had no effect on ground water profiles at distances greater than 12 feet from the ditch. Other studies indicate wide variation in soils referred to as the "Bladen Series" along the South Atlantic Coast.

---

[2]A new book "Physiology of Trees" by P. J. Kramer and T. T. Kozlowski (McGraw-Hill, 1960), published after submittal of this paper, gives an excellent literature review of this subject.

On Bladen and similar soils, differences in vegetative stocking are reported as affecting the drawdown rates of water tables during a rain-free summer period. The rates ranged from 0.14 to 0.09 feet per day, depending upon the proximity of the water table to root concentrations. Drawdown during the growing season, caused principally by evapotranspiration, appeared to be three to four times that of drainage alone.[3]

Rainfall at the study area for 1957 was 52 inches; and for 1958, 48 inches.

Description of Main Experiment

One-year-old slash and loblolly pine seedlings were planted at 2 x 2 foot spacing in mid-February 1957, in previously prepared 12 x 24 foot diked and ditched plots. The soil was undisturbed at time of planting. The whole plots were divided into 2 split plots, each randomly assigned 25 trees of one species. Nursery-grown stock from seed originating in the coastal area was used.

A severe four-month drouth preceded planting. Therefore, to improve survival chances, all seedlings were watered within five days. Twenty-four slash pines and 13 loblolly pines, less than 3 percent of the 1350 trees planted, died and were replaced by early March. Between planting and beginning of water treatments on May 31, average height of slash pine seedlings had increased 3.5 inches (to 7.5 inches) while loblolly had grown an average of 5.9 inches (to 11.8 inches). All growth measurements were made to the nearest inch—from the ground to the terminal bud. The difference in initial size of the two species was of such magnitude that subsequent results were expected to be strongly biased in favor of loblolly pine (Table 1).

Initial watering following planting, replanting, and favorable growing conditions for three and one-half months prior to establishment of water treatments insured strong, vigorous plants for study.

FIGURE 1. *A drainage plot at the time treatments began.*

The design consisted of 3 blocks of nine randomized treatment plots each.

Treatments (Fig. 1) were:

(a) Water level maintained 8 inches above mean plot elevation (+8),

(b) Water level maintained 4 inches above mean plot elevation (+4),

(c) Water level maintained at mean plot elevation (±0),

(d) Water level maintained 4 inches below mean plot elevation (—4),

(e) Water level maintained 8 inches below mean plot elevation (—8),

(f) Water applied to a three-inch depth at three-week cycles. Outlets were lowered daily ⅛ inch (drainage coefficient), plus evaporation (dr ⅛),

(g) Same as (f) with ¼-inch drainage coefficient (dr ¼),

[3]Gallup, L. E. Unpublished thesis. North Carolina State College, 1954.

(h) Same as (f) with ½-inch drainage coefficient (dr ½),

(i) Uncontrolled check plot on undisturbed soil (ck).

Flooding treatments were begun in early June 1957 and maintained throughout the balance of the two-year experiment, except for (a), which was concluded at the end of the first year. Drainage treatments (f), (g), and (h) were suspended in November 1957 and resumed on March 26, 1958, at the first indication of the breaking of dormancy.

Water from an artesian well was supplied through plastic piping of one-inch mains and three-quarter-inch laterals. Water levels were controlled by inverted siphon outlets from dikes or ditches which encircled the plots. The water supply to each plot had independent manually-operated inlet valves. The constant water level treatments were maintained to offset evaporation, transpiration, and seepage. Valves were adjusted to provide slight water movement through overflow outlets which had sufficient capacity to remove excess rainfall within 24 hours. Prior to lowering outlets in the drainage coefficient plots, evaporation was measured in a standard Weather Bureau pan for the preceding 24 hours and the amount added to the drainage coefficient.

Check plots adjacent to the diked areas received no treatment other than watering at time of planting to insure survival. However, ponding occurred on these plots for periods of a week or more on several occasions after heavy rains, but the plots were never flooded to three-inch depths, as were the drainage coefficient plots at three week intervals. The check plots were then at an intermediate soil moisture level throughout most of the growing season. The maximum variation in elevations within plots was 0.48 foot. Most plots did not vary more than 0.2 foot in elevation.

Movement of water through Bladen soil is known to be very slow. Thus, it was not generally necessary to puddle core trenches under levees, which were 18 inches high with an 18-inch top width and a 1:1 side slope. Where fill material did not bond with top soil, causing seepage along lines of cleavage, cores were puddled through the top soil. Crayfish (*Cambarus* sp.) were a problem on some plots: they tunneled under levees, making holes over an inch in diameter through which water temporarily escaped.

Survival counts were taken monthly and heights of seedlings measured at time of planting and periodically thereafter.

Water temperatures on +4 and +8 plots were recorded on five days each month and whenever atmospheric temperatures exceeded 90°F the first year, and about every three days during the second growing season. At the same time —about 3:30 pm—air temperatures were observed above the plots.

Determination of dissolved oxygen in standing (semi-stagnant) water was made for samples withdrawn on three occasions from the +8 treatments. For comparison, dissolved oxygen was determined for artesian water (source for treatments), water from a nearby running stream, stagnant water ponded in the forest, and stagnant water in an open field. The Solvay (1957) Method 22 (Winkler $MnSO_4$) method was employed.

The study was terminated after two years because it was evident that, on the plots with better growth, crowns of seedlings would be interlocked before the end of the third growing season.

Supplementary Study

Because few seedlings survived in the three plots flooded to eight-inch depths from June 1957 to January 1958, further observations would serve no useful purpose. These plots were then drained on January 30, 1958, and a supplementary study installed in mid-February to determine (a) whether slash and loblolly pine seedlings can survive if planted on waterlogged Bladen soil immediately after surface drainage is provided, and (b) whether

TABLE 1. Mean number of surviving seedlings with drainage and constant water level treatments. (25 = 100 percent). (Number of days refers to the time since treatment began on May 31, 1957.)

No		Constant water levels					Drainage coefficients			check	LSD[1]		Anal. of Vairance[1]		
days	Species	+8	+4	±0	−4	−8	1/8	1/4	1/2		5%	1%	Treat.	Sp.	Sp. x Tr.
41	Slash	23.0	24.3	24.3	23.0	22.7	23.7	23.3	23.3	23.0					
	Loblolly	24.7	25.0	24.7	25.0	25.0	24.3	24.7	24.7	25.0	2.2	3.0			
	S + L	23.8	24.7	24.5	24.0	23.8	24.0	24.0	24.0	24.0	2.9	3.9	ns	**	ns
68	Slash	17.0	24.3	24.0	23.0	22.7	23.7	22.7	23.0	22.7					
	Loblolly	24.7	25.0	24.7	25.0	25.0	24.3	24.7	24.7	25.0	3.1	4.3			
	S + L	20.8	24.6	24.3	24.0	23.8	24.0	23.6	23.8	23.8	0.9	1.2	**	ns	*
101	Slash	5.3	23.7	23.0	22.7	22.3	23.3	22.7	22.3	22.7					
	Loblolly	22.7	24.3	24.7	25.0	25.0	24.3	24.7	24.3	24.7	3.6	4.9			
	S + L	14.0	24.0	23.8	23.8	23.6	23.8	23.6	23.3	23.6	2.4	3.3	**	**	**
133	Slash	7.7	23.0	22.7	22.7	21.3	22.7	22.7	22.3	22.3					
	Loblolly	19.3	22.7	24.3	25.0	25.0	24.3	24.7	23.3	24.3	5.0	6.8			
	S + L	13.5	22.8	23.5	23.8	23.2	23.5	23.6	22.8	23.3	3.1	4.2	**	**	ns
166	Slash	7.7	20.7	21.7	22.7	21.3	22.7	22.3	22.3	22.3					
	Loblolly	16.0	17.7	24.3	25.0	25.0	24.3	24.7	23.0	24.3	5.5	7.6			
	S + L	11.8	19.2	23.0	23.8	23.2	23.5	23.5	22.7	23.3	4.6	6.3	**	*	ns
206	Slash	3.0	17.7	20.3	22.7	21.3	20.3	21.3	19.7	22.0					
	Loblolly	13.7	15.3	23.3	25.0	25.0	24.3	24.3	22.3	24.3	3.4	4.7			
	S + L	8.3	16.5	21.8	23.8	23.2	22.3	22.8	21.0	23.2	5.8	8.0	**	**	**
245	Slash		14.0	19.3	22.0	21.3	20.0	18.7	18.0	21.7					
	Loblolly		14.7	23.3	25.0	25.0	24.3	24.0	21.7	24.3	3.5	4.9			
	S + L		14.3	21.3	23.5	23.2	22.2	21.3	19.8	23.0	3.1	4.4	*	**	ns
277	Slash		18.0	19.7	22.0	21.0	21.7	20.7	21.3	21.3					
	Loblolly		10.0	23.0	25.0	24.7	24.3	24.0	21.3	24.3	4.7	6.4			
	S + L		14.0	21.3	23.5	22.8	23.0	22.3	21.3	22.8	4.3	6.0	**	ns	*
304	Slash		18.7	19.3	21.7	21.0	22.0	22.0	20.3	21.0					
	Loblolly		9.7	22.3	24.7	24.7	24.3	24.0	20.3	24.3	4.6	6.3			
	S + L		14.2	20.8	23.2	22.8	23.2	23.0	20.3	22.7	4.4	6.0	**	ns	*
335	Slash		18.7	19.3	21.7	21.0	21.7	22.3	20.7	21.3					
	Loblolly		9.0	22.0	24.7	24.7	24.3	24.0	20.7	24.3	4.5	6.3			
	S + L		13.8	20.7	23.2	22.8	23.0	23.2	20.7	22.8	2.9	4.1	**	ns	**
369	Slash		18.7	18.7	21.7	21.0	21.7	22.0	20.0	21.0					
	Loblolly		9.0	22.0	24.7	24.3	24.3	22.3	20.7	24.3	4.1	5.6			
	S + L		13.8	20.3	23.2	22.7	23.0	22.2	20.3	22.7	4.3	6.0	**	ns	**
398	Slash		18.3	18.7	21.7	21.0	21.7	21.3	19.7	21.0					
	Loblolly		8.7	21.7	24.7	24.3	24.3	22.3	20.7	24.3	4.2	5.8			
	S + L		13.5	20.2	23.2	22.7	23.0	21.8	20.2	22.7	3.1	4.3	**	ns	**
431	Slash		17.7	18.0	21.7	21.0	21.7	21.3	19.7	21.0					
	Loblolly		8.3	21.7	24.7	24.3	23.7	22.0	20.7	24.3	4.4	6.1			
	S + L		13.0	19.8	23.2	22.7	22.7	21.7	20.2	22.7	3.1	4.3	**	ns	**
459	Slash		17.3	17.7	21.7	21.0	21.3	21.3	19.7	20.0					
	Loblolly		8.3	21.7	24.3	24.3	23.7	21.7	20.7	24.3	4.2	5.8			
	S + L		12.8	19.7	23.0	22.7	22.5	21.5	20.2	22.2	3.1	4.4	**	ns	**
489	Slash		16.3	17.7	20.7	20.7	21.0	20.7	19.7	19.7					
	Loblolly		7.7	21.3	24.3	23.7	23.7	20.7	20.7	24.3	4.7	6.5			
	S + L		12.0	19.5	22.5	22.2	22.3	20.7	20.2	22.0	3.1	4.2	**	ns	**
518	Slash		16.0	17.3	20.7	20.7	21.0	20.7	19.3	19.7					
	Loblolly		7.0	21.3	24.3	23.7	23.3	20.3	20.7	24.3	4.5	6.2			
	S + L		11.5	19.3	22.5	22.2	22.2	20.5	20.0	22.0	2.9	4.1	**	ns	**
550	Slash		16.0	17.0	20.7	20.3	21.0	20.3	18.3	19.7					
	Loblolly		6.3	21.3	24.0	23.7	23.3	20.3	20.7	24.3	4.2	5.8			
	S + L		11.2	19.2	22.3	22.0	22.2	20.3	19.5	22.0	3.5	4.9	**	ns	**

[1]LSD = Least Significant Difference at the respective levels for recording statistical variance between any two figures in the line, or lines, for which the LSD's are given. One asterisk indicates 5 percent level and two asterisks indicate 1 percent level. Replication was not significant at all periods.

seedlings, subjected to 8-inch flooding for periods of 2, 4, and 8 weeks will survive after drainage. As only these three plots were available, range in duration of flooding was sought, rather than replication. One hundred seedlings of each species were planted in each plot at 1 x 1 foot spacing. During the two-week interim between draining and planting, a crust formed on the soil which would temporarily support a man; but the trampling during hand-planting left the soil mushy. Machine planting would have been impossible under these conditions. As in 1957, seedlings were permitted to grow until June before being subjected to flooding. Loblolly pine seedlings were from seed from a single tree, slash pine seedlings were common stock.

Results and Discussion

Survival. Few seedlings died during the first 41 days, from May 31 to July 11, even on plots flooded to a depth of 8 inches above mean plot elevations. Nevertheless, highly significant differences were noted between species (Table 1). Appreciable mortality was first observed for slash pine on the +8 plots 68 days after treatment began. For loblolly pine, it was observed at 133 days on both +4 and +8 plots. Of the slash pine seedlings, 64 percent survived at the end of the experiment.

Seedling heights seemed important to survival. For the first year, loblolly pine seedlings survived better than slash pine under flooded conditions, possibly because the loblolly pines were taller when treatments began. By rearranging height and survival data, we found a relationship between height of terminal bud above the water surface and the time required for flooding to kill pine seedlings during the first year (206 days), regardless of species (Fig. 2). Much of the difference in survival occurred in the +8 treatments, where slash pine heights averaged 0.9 inch less than the water level. The loblolly seedlings for this treatment averaged 4.0 inches above the water. Slash pine so treated (+8) had survival rates significantly lower (1 percent level) than for all other treatments. Loblolly pine seedlings averaging 6.6 inches above water level also had lower survival rates than those which averaged 11.0 inches above that point. Between other seedling heights, as related to water level, no significant differences either within or between species were apparent. The interaction between species and treatments, although statistically significant in August (68 days), September (101 days), and December (206 days) of the first year is, therefore, not of real importance. It is possible that the same reasoning would hold for the significant interaction found at the first measurement of the second year (245 days).

Following the first 41 days of treat-

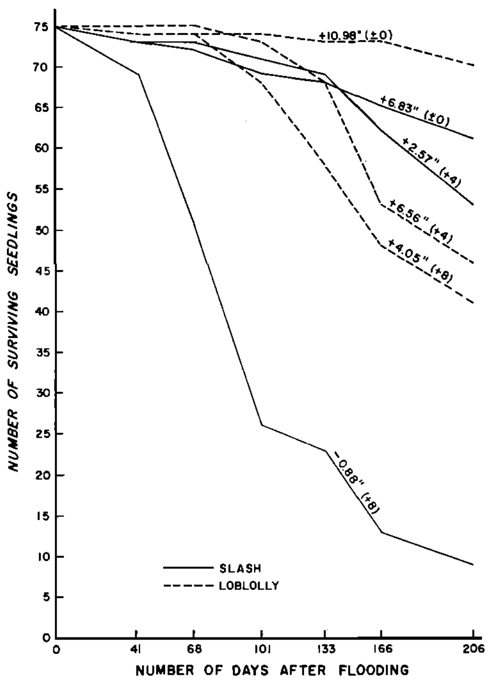

FIGURE 2. *Relation between height of seedlings above water surface and their survival with respect to time. Treatments are shown in parentheses. The number of seedlings at the time flooding began was 75 in each case. L.S.D.—5 percent = 8.6; 1 percent = 11.6.*

ment, trees died at an increasing rate on plots flooded to depths of 4 and 8 inches and by 206 days practically all seedlings on the +8 plots were dead. Only 66 percent survived on the +4 plots. On the ±0 plots, survival was 87 percent, and all other treatments were above this acceptable minimum. In the 27 days following the first 41, from July 11 to August 7, the differences between treatments taken together became highly significant and remained so. At no time during the first growing season was there a significant difference in survival between the check plots, the three drainage coefficient treatments, or the three constant water level drainage treatments (±0, −4, −8).

The amount of drainage appeared unimportant to survival at the end of the experiment, as long as seedlings were not continuously flooded. In December 1958, 550 days after establishing water control treatments, there were still no significant differences between treatments or species except for the +4 treatment. For slash pine, survival was definitely inferior on the +4 to the −4, −8, dr 1/8, and dr 1/4 plots. But no significance was shown between these two drainage treatments and the dr 1/2 treatments. For loblolly pine, the +4 plots exhibited poorer survival than did all other treatments. (It will be recalled that the +8 plots were previously abandoned.) Slash pine survival was better than loblolly pine (1 percent level) on the +4 treatments and inversely so on the ±0 plots. Yet, for all treatments combined, species differences were not apparent.

In the supplementary study average survival 4 months after planting, when treatment began on June 6, was 69.3 percent for slash pines and 96.0 percent for loblolly pines. This is similar to the main study survival observation—that the slash pine stock employed here apparently required a more favorable planting environment than did the loblolly pine for equal chances of survival. Loblolly pine seedlings temporarily withstood inundation better than slash pine. On water-logged soil flooded to depths of 8 inches—approximately the height of terminal buds—survival was better for loblolly pine only as long as submergence continued (Table 3). This held especially for the 4- and 8-week inundation periods. The initial advantage of loblolly pine was then offset by its higher mortality after drainage began. In all three plots, survival of slash pine 6 weeks after the plots were drained slightly exceeded that of loblolly pine, and this difference persisted. Eighteen weeks after the 2-week flooding period was over, slash pine seedling survival was 76 percent and loblolly pine 60 percent. This indicates that trees with an 8-inch inundation for 2 weeks in June may have such a low survival as to require subsequent replanting (Fig. 3). It is possible, however, that flooding earlier in the year, when water temperatures are lower, would have less severe effects.

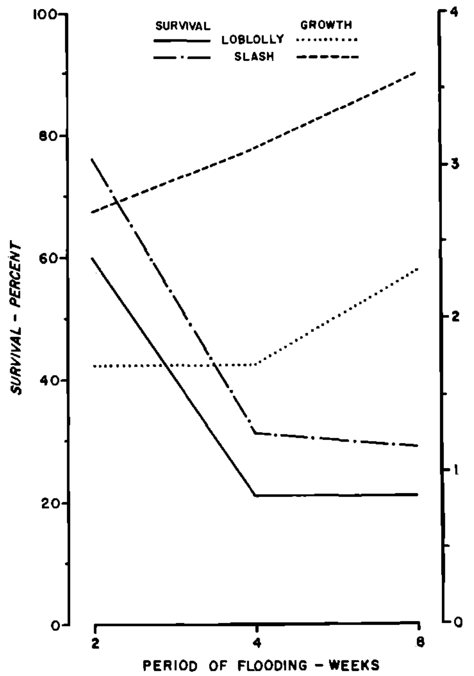

FIGURE 3. *Survival and growth of seedlings 18 weeks after the three 8-inch flooding treatments ceased (supplementary study).*

Growth. Height growth of pines in the flatwoods continues throughout the season in which pines are normally considered dormant. While it was first believed that early October approximates the inception of winter dormancy in the southeastern Tidewater area, trees in several plots measured on November 13, 1957 had grown twice as much in the 33 days since October 11 as in the previous 133 days. Because these data contradicted anticipations, it was decided to make growth measurements monthly. As survival was low for plots flooded to a depth of 8 inches, growth data for these treatments are omitted to permit a more accurate analysis of variance between other treatments.

On October 11, 133 days after establishment of water treatments, the first height measurements were made and net growth of surviving trees determined. At that time slash pine height growth ranged from 0.3 inch on the ±0 plots to 3.0 inches on the −8 plots. Loblolly pine averaged 0.7 inch on the ±0 treatment and 4.0 inches on the check plots. Treatment responses were significantly different (1 percent level), as was the interaction between species. Species x treatment interaction, however, was significant at the 5 percent level, while variation among replicates of the same treatment was not.

FIGURE 4. *Slash pine seedlings at conclusion of the experiment. From left to right: ±0, +4, −8, and check treatments.*

The −8 treatment was best for slash and loblolly pine height growth combined. Highly significant differences were found between the +4 and −4, +4 and −8, +4 and ck, ±0 and −4, ±0 and −8, ±0 and ck, −4 and dr ½, −8 and dr ½, and ck and dr ½ treatments. For each succeeding date of measurement, and for each species, these statistical variances are readily determined from the figures on least significant difference (LSD) in Table 2.

Treatment differences remained highly significant throughout the study. The statistical difference between species disappeared after the first measurement; but early in the second year, when replication variance appeared, species difference became highly significant and remained so until the conclusion of the experiment. Near the end of the study replication variance was found highly significant. No consistency was noted for the species x treatment interaction.

At the end of the study, slash pine height growth ranged from 4.4 inches on the ±0 plot to 19.7 inches where drainage was to a depth of 8 inches (Fig. 4). Loblolly pines behaved similarly, being smallest (6.2 inches) on the ±0 plot, and 21.8 inches on the −8 plot. The trend in growth for slash pine from least to best was: ±0, dr ¼, +4, dr ½, dr ⅛, ck, −4, and −8. For loblolly, it was ±0, dr ¼, dr ½, dr ⅛, +4, ck, −4, and −8. Extreme plot conditions at the end of the tests are shown in Figure 5.

Throughout the first year loblolly pine seedling growth was best on the check plots. Not until over 15 months (459 days) had elapsed was the −8 treatment found to be better. Perhaps the second growing season was more typical for judging the effect of poor natural drainage

TABLE 2. Average growth, in inches, of surviving seedlings with drainage and constant water level treatments. (Number of days refers to the time since treatment began on May 31, 1957.)

No		Constant water levels				Drainage coefficients			check	LSD[1]		Anal. of Variance[1]			
days	Species	+4	±0	−4	−8	⅛	¼	½		5%	1%	Repl.	Treat.	Sp.	Sp. x Tr.
133	Slash	0.6	0.3	2.0	3.0	1.4	0.6	0.6	1.6	1.4	1.9				
	Loblolly	1.0	0.7	2.6	2.0	1.7	1.6	0.9	4.0	0.9	1.3				
	S + L	0.8	0.5	2.3	2.6	1.6	1.1	0.7	2.8			ns	**	**	*
166	Slash	2.0	1.7	3.7	4.1	2.7	1.6	2.0	2.4	1.9	2.6				
	Loblolly	1.7	1.9	4.1	3.1	2.9	2.6	1.9	5.1	1.3	1.9				
	S + L	1.8	1.8	3.9	3.6	2.8	2.1	1.9	3.8			ns	**	ns	ns
206	Slash	2.9	2.2	4.2	5.0	3.7	2.5	2.7	3.3	1.5	2.1				
	Loblolly	2.7	2.2	4.4	3.7	3.2	3.0	2.3	5.7	0.9	1.2				
	S + L	2.8	2.2	4.3	4.4	3.4	2.7	2.5	4.5			ns	**	ns	ns
245	Slash	4.1	2.8	4.5	5.4	4.0	3.4	3.4	3.8	1.4	1.9				
	Loblolly	3.0	2.7	4.7	4.2	3.4	3.3	2.6	6.1	1.0	1.3				
	S + L	3.6	2.7	4.6	4.8	3.7	3.3	3.0	4.9			ns	**	ns	*
277	Slash	3.2	2.7	4.5	5.5	3.7	3.0	2.8	3.8	1.7	2.3				
	Loblolly	5.5	2.6	4.7	4.2	3.4	3.3	2.6	6.1	1.2	1.7				
	S + L	4.3	2.7	4.6	4.8	3.6	3.1	2.7	5.0			ns	**	ns	ns
304	Slash	3.2	2.8	4.9	5.6	3.7	2.8	3.0	4.1	1.5	2.1				
	Loblolly	5.3	2.7	4.8	4.3	3.4	3.3	2.9	6.3	0.8	1.1				
	S + L	4.2	2.7	4.9	5.0	3.5	3.1	2.9	5.2			ns	**	ns	*
335	Slash	3.5	3.1	8.2	9.7	4.7	3.2	3.7	6.9	2.1	2.9				
	Loblolly	6.2	3.6	10.4	9.9	4.9	4.5	4.3	12.2	1.7	2.3				
	S + L	4.9	3.4	9.3	9.8	4.8	3.8	4.0	9.5			*	**	**	*
369	Slash	3.6	3.3	9.4	11.5	5.2	3.4	4.1	7.8	2.3	3.2				
	Loblolly	6.3	4.2	13.5	13.3	5.6	5.3	5.2	14.3	2.0	2.7				
	S + L	4.9	3.8	11.5	12.4	5.4	4.4	4.7	11.1			*	**	**	*
398	Slash	3.8	3.6	11.1	13.7	5.5	3.7	4.7	9.0	2.7	3.7				
	Loblolly	6.7	5.1	15.8	16.1	6.3	5.7	6.2	16.5	2.6	3.6				
	S + L	5.2	4.3	13.5	14.9	5.9	4.7	5.4	12.8			*	**	**	*
431	Slash	4.0	3.9	12.9	16.1	5.7	3.8	4.9	10.6	2.2	3.0				
	Loblolly	7.1	5.5	18.2	18.6	6.8	6.0	6.7	18.8	2.8	3.8				
	S + L	5.6	4.7	15.5	17.3	6.2	4.9	5.8	14.7			*	**	**	*
459	Slash	4.1	3.9	13.4	17.2	5.8	3.9	4.9	11.5	4.2	5.8				
	Loblolly	7.1	5.7	19.5	19.9	6.9	6.1	6.7	19.6	2.9	4.0				
	S + L	5.6	4.8	16.4	18.6	6.3	5.0	5.8	15.6			*	**	**	*
489	Slash	4.4	4.0	14.5	18.1	5.9	4.1	5.1	12.1	3.6	4.9				
	Loblolly	8.9	5.9	20.2	21.0	7.0	6.5	6.8	19.9	2.3	3.1				
	S + L	6.7	5.0	17.4	19.5	6.5	5.3	5.9	16.0			**	**	**	ns
518	Slash	4.8	4.2	15.2	18.7	6.3	4.3	5.6	12.6	3.4	4.6				
	Loblolly	9.2	6.0	20.7	21.5	7.4	6.8	7.1	20.1	3.4	4.7				
	S + L	7.0	5.1	18.0	20.1	6.9	5.5	6.4	16.3			*	**	**	ns
550	Slash	4.8	4.4	15.6	19.7	6.4	4.6	6.3	13.0	3.2	4.4				
	Loblolly	9.6	6.2	21.2	21.8	7.5	6.9	7.3	20.4	3.6	5.0				
	S + L	7.2	5.3	18.4	20.8	6.9	5.7	6.8	16.7			*	**	**	ns

[1] LSD = Least Significant Difference at the respective levels for recording statistical variance between any two figures in the line, or lines, for which the LSD's are given. One asterisk indicates 5 percent level and two asterisks indicate 1 percent level.

since critical drouth conditions did not need to be overcome, as was the case the first year. If the first year had been normal, it is doubtful that check plot growth would have been superior to the ±0 treatments. Firm seedling establishment during the first year, moreover, enabled satisfactory growth despite excess water the second year.

The pretreatment first-year drouth left soil moisture depleted to the degree that abundant rainfall could be absorbed and retained by the soil without a serious flood condition occurring on the check plots.

FIGURE 5. *An 8-inch plot, showing loblolly pines at the end of the second growing season (left), and a +4-inch plot with hydrophytic vegetation and stunted seedlings (right).*

Also, adequate rainfall well distributed during the growing season favorably influenced survival and growth. If the particular season sampled had heen normal, this might imply that for loblolly pine no drainage is needed other than the elimination of permanent ponding. However, average growth on plots with water at —8 inches and —4 inches was almost as much as for the check early in the second

TABLE 3. Survival and growth of seedlings with eight-inch water level treatments in the supplementary study on water-logged soil. Growth calculations (inches) are cumulative with time for surviving seedlings. Survival percentages are based upon trees living at the begining of treatment.

	2-week treatment				4-week treatment				8-week treatment			
	Slash		Loblolly		Slash		Loblolly		Slash		Loblolly	
	Sur.	Gr.	Sur.	Gr.	Sur.	Gr.	Sur.	Gr.	Sur.	Gr.	Sur.	Gr
	Percent	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*	*Percent*	*Inches*
End of treatment	95	0.4	100	0.4	51	1.2	96	0.9	39	2.9	53	1.9
End of treatment plus 6 weeks	77	2.1	70	1.3	31	2.1	23	1.2	29	3.4	24	2.3
End of treatment plus 12 weeks	76	2.6	61	1.6	31	2.3	21	1.2	29	3.5	22	2.3
End of treatment plus 18 weeks	76	2.7	60	1.7	31	3.1	21	1.7	29	3.6	21	2.3

growing season (335 days), and these three treatments were significantly better (1 percent level) than all others.

Slash pine seedlings, in contrast, had their greatest growth during the entire experiment on −8 plots, although this was not significantly greater than for the −4 treatment. It was, however, significantly more (5 percent level) than on the check plots. Slash pine growth on the check plot was at an intermediate level among all treatments. As stated previously, the variation between species was probably due to the initial difference in the size and apparent vigor of the stock, the loblolly pine being much superior. This, of course, does not account for the disappearance of significance during the period from 166 to 304 days after treatments began.

Growth was slightly better for both species on +4 plots than on the ±0. While slash pine growth on −8 plots was slightly superior to loblolly pine the first year, the opposite occurred the second year. The better growth of loblolly pine than slash pine on the drained plots may indicate that the former is benefited most by drainage in the seedling stage or, again, the larger stock may have been responsible.

Another trend for both species under the coefficient treatments was towards higher average growth with the slowest drainage rate of ⅛-inch per day, though the differences were not significant at any time during the experiment. A coefficient of ⅛-inch is lower than that now used by drainage engineers.

Different water treatments appear to have had little effect on the duration of dormancy. A small amount of growth occurred in January, virtually none in February, and some in March. April was the period of spring flush, and through July of the second year, rapid growth continued on check plots and for −4 and −8 treatments.

In the supplementary study, average growth of slash pine was greater than for loblolly pine at every period of measurement after plots were drained (Table 3). Both species averaged 7.2 inches in height at time of treatment on June 6. This was approximately 0.8 inch less than the depth of flooding. During each period of submergence, growth of surviving slash pine seedlings was equal to, or greater than, that of loblolly pine (Fig. 3).

Temperatures. High survival rate on one +8 plot the first year may have been due to its lower water temperatures. This plot also had abnormally favorable height growth, judging from the growth of seedlings in its replicates. Therefore, detailed temperature measurements were made about every three days during the second growing season to confirm the results from limited data collected the first year. Should further testing substantiate that pines are so sensitive to water temperatures, a practical aspect would be the greater need for elimination of ponding in open fields than where partial shade occurs.

Water temperatures were usually about 2° to 5°F warmer than the air, but on occasion differences of 13°F were recorded. Prior to October, only for the single plot mentioned above was the water temperature cooler than the air, the difference averaging 4°F. During October and November, ambient temperature generally exceeded water temperature. Temperature in the air above flooded plots varied as much as 7°F while water temperatures differed as much as 11°F (Fig. 6). No reason is surmised for these differences during the first year of treatment other than the effect of some shading from a woodland on the west and a shrub hedge to the east of the plots. The temperature variation between plots continued through 1958, and again water temperatures tended to be higher than air temperatures.

Oxygen. Dissolved oxygen in the water of the +8 treatments, as well as in the comparison samples, was extremely inconsistent. In the flooded plots, it ranged from 2.8 to 8.3 mg per liter. Stagnant

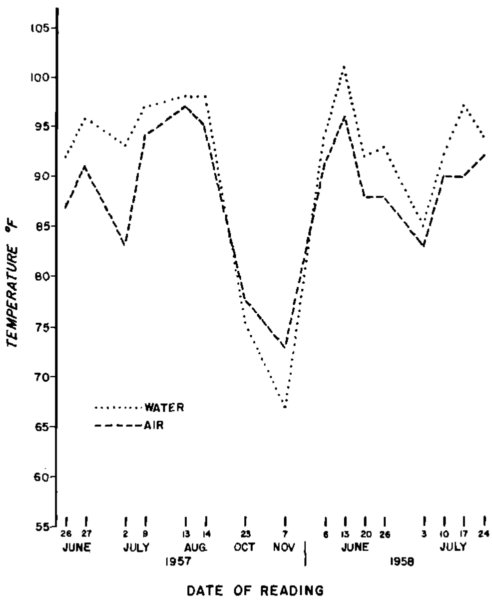

FIGURE 6. *Average air and water temperatures of plots flooded to depths of four and eight inches.*

ponds with timber contained about 5 mg, ponds in the open 7 mg, running streams 7 mg, and the artesian water source ranged from 3.7 to 8.3 mg at the outlet. While poor aeration may have limited growth in the flooded plots, the amount of free oxygen present generally exceeded the requirements for growing plants hydroponically.

Summary and Conclusions

Slash and loblolly pine seedlings planted in a plastic clay loam soil were continuously flooded to ± 0, 4, and 8-inch depths; continuously drained to 4 and 8 inches below ground level; and flooded to a depth of three inches at 3-week intervals with subsequent drainage at ⅛, ¼, and ½-inch per day coefficients.

A supplemental study tested survival ability of slash and loblolly pine seedlings planted on waterlogged soil immediately after drainage, but subjected to subsequent 2-, 4-, and 8-week periods of inundation to 8 inches.

Results and suggested practical conclusions are:

1. Mortality was inversely related to height of seedlings. Moreover, it appears that terminal buds must be above water to survive more than a few weeks of inundation.

2. Slash pine seedlings in the plots began to die 68 days after initiation of flooding to 8-inch depths, and loblolly pine within 133 days. Flooding to 8-inch depths resulted in severe mortality, while flooding to 4-inch depths caused significant losses the first year. Slash pine inundated for periods longer than two months and loblolly pine for four months will probably require replanting.

3. One-year-old seedlings of slash and loblolly pine averaging 7.2 inches tall endured a maximum of 2 weeks under 8 inches of water without excessive mortality in the supplemental study. To permit seedling survival, previously water-logged sites, now drained, will require surveillance to guard against prolonged subsequent inundation to depths of 8 inches and over.

4. First year height growth of loblolly pine on plots continuously drained to 4 and 8 inches below ground level considerably exceeded growth where water constants were maintained at ground level and at 4 and 8 inches above that point. Best growth of slash pine was on plots with drainage to a depth of 8 inches, although it was not significantly different than for a 4-inch depth. By the end of the second year, greatest growth for both species was on the plots drained to 8 inches below ground level. Maintaining ground water at a depth of 4 inches, however, appears satisfactory for young seedlings.

5. Among drainage coefficient plots, no real differences occurred between rates of water removal of ⅛, ¼, and ½ inch per day. One-eighth inch coefficients appear satisfactory for seedling establishment.

6. Growth of slash pine exceeded that of loblolly pine following drainage of all plots inundated from 2 to 8 weeks, indicating a greater ability of the former to

withstand unfavorable water conditions.

7. Trees in several plots grew twice as much from October 11 to November 13 as in the 133 days prior to October 11.

Literature Cited

AHLGREN, C. E., and H. L. HANSEN. 1957. Some effects of temporary flooding on coniferous trees. J. For. 55: 647-650.

BERGMAN, H. F. 1920. The relation of aeration to the growth and activity of roots and its influence on the ecesis of plants in swamps. Ann. Bot. 34: 13-33.

DEAN, B. ELIZABETH. 1933. Effect of soil type and aeration upon root systems of certain aquatic plants. Plant Physiol. 8: 203-222.

DEMAREE, DELZIE. 1932. Submerging experiments with Taxodium. Ecol. 13: 258-262.

GREEN, W. E. 1947. Effect of water impoundment on tree mortality and growth. J. For. 45: 118-120.

HUNT, F. M. 1951. Effect of flooded soil on growth of pine seedlings. Plant Physiol. 26: 363-368.

JACKSON, W. T. 1956. The relative importance of factors causing injury to shoots of flooded tomato plants. Amer. J. Bot. 43: 637-639.

KOZLOWSKI, T. T. 1958. Water relations and growth of trees. J. For. 56: 498-502.

KRAMER, P. J. 1933. The intake of water through dead root systems and its relation to the problem of absorption by transpiring plants. Amer. J. Bot. 20: 481-492.

————. 1949. Plant and Soil Water Relationships. McGraw-Hill Book Co., N. Y. pp. 150, 220 *et. fol.*

————. 1951. Causes of injury to plants resulting from flooding of the soil. Plant Physiol. 26: 722-736.

KUSTER, A. 1948. Der Einfluss der Juraseen-Hochwasser auf die Strandwaldungen. Schweiz. Z. Forstw. 99: 428-438.

LEYTON, L., and L. Z. ROUSSEAU. 1958. Root growth of tree seedlings in relation to aeration. *In* The Physiology of Forest Trees. Ronald Press, N. Y.

PARKER, J. 1950. The effects of flooding on the transpiration and survival of some southeastern forest tree species. Plant Physiol. 25: 453-460.

PRUITT, A. A. 1947. Study of effects of soils, water table, and drainage on the height growth of slash and loblolly pine plantations on the Hoffmann Forest. J. For. 45: 836.

SATTERLUND, D. R., and S. A. GRAHAM. 1957. Effect of Drainage on Tree Growth in Stagnant Bogs. Mich. For. No. 19. U. Mich., Ann Arbor.

SCHLAUDT, E. A. 1955. Drainage in forestry management in the South. *In* Water. Yrbk. of Agric., U. S. Dept. Agric.

SCOTT, A. D., and D. D. EVANS. 1955. Dissolved oxygen in saturated soil. Soil Sci. Soc. Amer. Proc. 19: 7-12.

SOLVAY Co. 1957. Water Analysis. Technical and Engineering Service Bull. 11.

STONE, E. L., R. R. MORROW, and D. S. WELCH. 1954. A malady of red pine on poorly drained sites. J. For. 52: 104-113.

TROUSDELL, K. B., and M. D. HOOVER. 1955. A change in groundwater level after clearcutting of loblolly pine in the Coastal Plain. J. For. 53: 493-498.

YEAGER, L. E. 1949. Effect of Permanent Flooding in a River Bottom Timber Area. Ill. Nat. Hist. Surv. Bull. 25, Art. 2.