EARLY RELEASE IMPROVES LONG-TERM GROWTH AND DEVELOPMENT OF DIRECT-SEEDED NUTTALL OAK SAPLINGS

James S. Meadows, Robert L. Johnson, and Roger M. Krinard[1]

Abstract-- Early growth of bottomland oaks is typically slow, and many oaks eventually become overtopped by trees of other species. Removal of these larger competitors in a young stand might improve growth of the oaks and lead to more free-to-grow oaks as the stand matures. Release treatments were applied in 1980 to an 11-year-old, direct-seeded Nuttall oak (*Quercus texana* Buckl.) plantation on a Sharkey clay soil in west-central Mississippi. Treatments consisted of either cutting or deadening all non-oaks more than 15-feet tall, more than 20-feet tall, and more than 25-feet tall, plus an unreleased control. The average height of free-to-grow Nuttall oaks at the time of treatment was 15 feet. Response data were collected annually for the first 9 years after release, at 11 years after release, and at 30 years after release. Release treatments that removed competitors more than 15-feet tall and those that removed competitors more than 20-feet tall significantly increased stand basal area and quadratic mean diameter of the plantation but did not significantly increase either pulpwood or sawtimber volume per acre, even though differences among treatment means appeared to be large. Release treatments that removed competitors more than 20-feet tall were as effective but less costly than those treatments that removed competitors more than 15-feet tall.

INTRODUCTION

Early growth of bottomland oaks is typically slow. Consequently, many oaks eventually become overtopped by faster-growing trees of other species. Precommercial removal of these larger competitors in a young stand might improve growth of the oaks and encourage the development of more free-to-grow (trees with full sunlight directly overhead) oaks as the stand matures. However, there is a lack of knowledge about how young oaks grow and develop in competition with trees of other species in even-aged stands. If the oaks are unable to overcome early suppression by faster-growing trees of other species, some form of precommercial release cutting will be necessary to assure satisfactory oak development into the overstory of the stand.

Crop-tree release, in which pre-selected crop trees of desirable species are released fully from overhead competition and partially from side competition, has been used successfully to improve growth and development of overtopped saplings of several hardwood species. For example, Downs (1942) reported that crop-tree release stimulated diameter growth and reduced crown class regression in sugar maple (*Acer saccharum* Marsh.), white oak (*Quercus alba* L.), and yellow-poplar (*Liriodendron tulipifera* L.) saplings in the southern Appalachian Mountains. Conover and Ralston (1959) found that a sequence of two crop-tree release cuttings, spaced 8 years apart, increased long-term diameter growth of American elm (*Ulmus americana* L.), white ash (*Fraxinus americana* L.), and American basswood (*Tilia americana* L.) saplings in an 11-year-old northern hardwood stand in Wisconsin.

Della-Bianca (1975) also described increased diameter growth of crop trees after an intensive crop-tree release cutting, in which all woody stems other than crop trees were cut in an 11-year-old mixed-hardwood stand in the southern Appalachian Mountains. Crop trees included various species of red oaks and white oaks, black locust (*Robinia pseudoacacia* L.), and red maple (*Acer rubrum* L.). However, effects of the release cutting on diameter growth of crop trees dissipated by the end of the sixth year after release. Della-Bianca (1975) observed that high-quality stands developed in both the released plots and unreleased control plots and concluded that release cuttings were not necessary to promote adequate oak development on medium-quality sites in the southern Appalachians.

However, efforts to release oak saplings from overtopping competition have not always been successful. For example, Lamson and Smith (1978) found that crop-tree release did not improve diameter growth nor prevent crown class regression in 9-year-old sugar maple, northern red oak (*Q. rubra* L.), black cherry

[1]Principal Silviculturist, Project Leader (retired), and Mensurationist (deceased), USDA Forest Service, Southern Research Station, Stoneville, MS 38776.

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(*Prunus serotina* Ehrh.), and yellow-poplar saplings in West Virginia. They concluded that crop-tree release is inadvisable on good sites in the southern Appalachians.

So, can direct-seeded Nuttall oak (*Q. texana* Buckl.) saplings overcome early suppression by faster-growing trees of other species and develop into the overstory of the stand without the assistance of silvicultural treatment? If not, will some form of precommercial release cutting be effective in promoting satisfactory oak development into the overstory? Insight into the first question may be provided by Oliver (1978), who described a pattern of natural stand development in undisturbed, even-aged, mixed-hardwood stands in New England. Initially, northern red oaks were overtopped by faster-growing red maple and black birch (*Betula lenta* L.). But the northern red oaks gradually overcame this early suppression and were able to out compete the other species as the stand developed. By age 60, northern red oaks dominated the stand and formed a continuous canopy above the other species. Clatterbuck and Hodges (1988) described a similar pattern of stand development for cherrybark oak (*Q. pagoda* Raf.) grown in mixture with sweetgum (*Liquidambar styraciflua* L.) on bottomland sites in Mississippi.

To address these questions, this study was initiated in 1980 to evaluate the effects of seven release treatments designed to favor the development of 11-year-old, direct-seeded Nuttall oak saplings in competition with naturally regenerated non-oaks of the same age. The goal of the release treatments was to increase the number of free-to-grow oaks per acre. Johnson and Krinard (1988) reported 6-year results of the study.

METHODS

Study Site

The study was established on a bottomland site within the Delta Experimental Forest in west-central Mississippi. Soil within the study site is Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts). It is poorly drained, slowly permeable, high in montmorillonitic clay, has a high shrink-swell capacity, and is dry in the summer and wet in the winter (Pettry and Switzer 1996). The site is flat and typically experiences annual backwater flooding for several weeks during the winter and spring. Floodwaters occasionally persist well into the summer. Broadfoot (1976) reported an average site index of 91 feet at 50 years for Nuttall oak.

Plantation Establishment

Before establishment of the Nuttall oak plantation, the study site supported a mature, mixed-species, bottomland hardwood stand dominated by American elm, green ash (*F. pennsylvanica* Marsh.), and sugarberry (*Celtis laevigata* Willd.), a typical species association on Sharkey clay flats. All merchantable timber was harvested, and the study site was cleared of all remaining vegetation and logging debris in the summer and fall of 1968. No other site preparation treatments were applied, but the study site was generally free of vegetation before plantation establishment.

The study site was sown with Nuttall oak acorns in the spring of 1969. Rows within the plantation are 10 feet apart; seed spots are spaced at 5-foot intervals within each row. Four Nuttall oak acorns were sown at each seed spot to ensure adequate oak stocking after anticipated high rates of acorn predation and expected low rates of seedling survival. Strips 5-feet wide were mowed down the center of the 10-foot-wide area between rows annually for the first 5 years after plantation establishment and again after the 10th year. This operation left an unmowed strip about 5-feet wide centered on each row. Naturally regenerated trees of various species became established in the unmowed strips and grew in direct competition with direct-seeded Nuttall oaks.

Treatments

Seven release treatments were applied in early 1980 when the plantation was 11 years old:

1. Cut all non-oaks more than 15 feet tall (C15+)
2. Deaden all non-oaks more than 15 feet tall (D15+)
3. Cut all non-oaks more than 20 feet tall (C20+)
4. Deaden all non-oaks more than 20 feet tall (D20+)
5. Cut all non-oaks more than 25 feet tall (C25+)
6. Deaden all non-oaks more than 25 feet tall (D25+)
7. Unreleased control - no cutting or deadening

Direct-seeded Nuttall oaks in the dominant or codominant crown classes averaged 15 feet in height at the time release treatments were applied. Consequently, treatments approximated the removal, through either cutting or deadening, of all non-oaks as tall as (C15+ and D15+), 1⅓ times as tall as (C20+ and D20+), and 1⅔ times as tall as (C25+ and D25+) direct-seeded Nuttall oaks in the dominant or codominant crown classes. Cutting of non-oaks was performed with a chainsaw between January and March 1980. Deadening of non-oaks was accomplished through injection with a mixture of 2,4-D and picloram in May 1980.

Study Design

Individual treatments were applied to three-row treatment plots in early 1980. However, only the center row of each treatment plot was measured. With 54 seed spots per row, the measurement plot consists of 0.062 acres.

Total height, diameter at breast height (d.b.h.), and crown class of every direct-seeded Nuttall oak greater than 4.5-feet tall were measured annually for the first 9 years and at the end of the 11th year after treatments were applied. Crown class, d.b.h., and merchantable height for either pulpwood or sawtimber were measured at the end of the 30th year after treatment. During each measurement event, data were collected for all variables on every direct-seeded oak at each seed spot within the measurement row. However, only data for the tallest tree at each seed spot were used in the statistical analyses.

Analysis of variance for a randomized complete block design with three replications of seven treatments was used to detect differences among treatments in trees per acre, basal area per acre, quadratic mean diameter, and the number of free-to-grow oaks per acre for each of the first 9 years and for the 11th and 30th years of the study. Free-to-grow oaks are defined as those direct-seeded oaks in the dominant or codominant crown classes. Pulpwood volume per acre and sawtimber volume per acre were analyzed for the 30th year only. Significance tests were conducted at the 0.05 level of probability. Treatment effects were considered fixed; block effects were considered random. Duncan's New Multiple Range Test was used to separate treatment means.

RESULTS AND DISCUSSION

Competitors

By the time the plantation was 11-years old, many direct-seeded Nuttall oaks had become overtopped by volunteer trees of other species. Before application of the release treatments in 1980, there were 283 free-to-grow oaks per acre, averaged across the plantation. In contrast, there were 937 competitors per acre that were taller than the average free-to-grow oak (nearly 15 feet). Green ash accounted for nearly half of all competitors more than 15-feet tall. Other common competitors included American elm, water hickory [*Carya aquatica* (Michx. f.) Nutt.], honeylocust (*Gleditsia triacanthos* L.), and sugarberry. The number of competitors removed during treatment decreased substantially with decreasing intensity of release (fig. 1). By implication, the cost required to apply the release treatments also decreased with decreasing intensity of release.

Response to Release Treatments

We found no significant differences among treatments in any of the response variables during any of the first 9 years after application of release treatments. Even though some means appeared to differ across treatments for some response variables during some years, high variability within the data resulted in large standard errors associated with most means and likely prevented detection of any statistical differences that may have existed among treatments.

The study site experienced a severe ice storm in February 1994 (14 years after application of release treatments). Many trees in the plantation suffered significant limb breakage in the crown. The stems of some trees snapped off at heights of 10 to 15 feet. Damage from the ice storm certainly affected growth and development of the direct-seeded Nuttall oak saplings. Consequently, beneficial effects of the release treatments that may have accrued to many trees in the plantation may have been negated by the ice storm.

Because we were unable to detect significant differences among treatments during the first 9 years of the study, the remainder of this paper describes conditions at the time of treatment and addresses responses only in the 11th and 30th years after release.

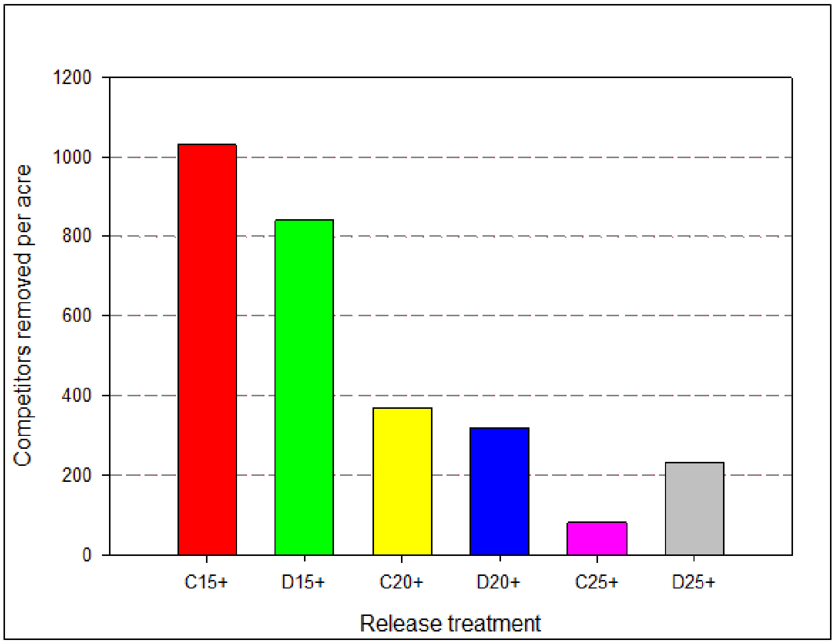

Figure 1--Number of competitors removed during application of release treatments.

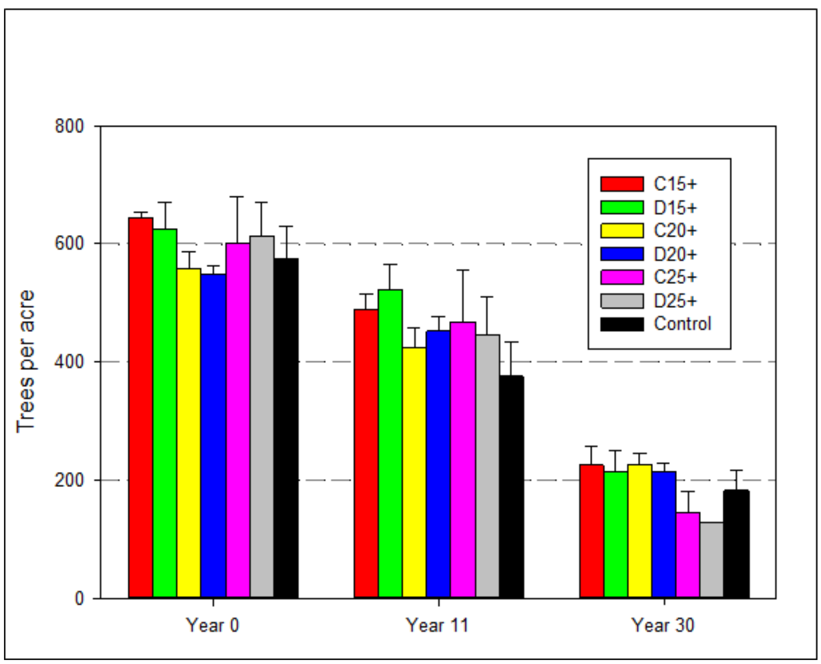

Figure 2--Number of Nuttall oak trees per acre (± SE), by treatment, immediately before release (year 0) and 11 and 30 years after application of seven release treatments. Means within each year followed by the same letter are not significantly different at the 0.05 level of probability.

Trees per acre--The plantation averaged 595 direct-seeded Nuttall oak trees per acre, across all plots, at the time the study was established. Plot means ranged from 548 to 645 trees per acre. We found no significant differences (p = 0.70) among plots prior to application of release treatments (fig. 2). Based on an initial density of 871 seed spots per acre, survival of direct-seeded oaks averaged 68 percent across all plots. Plot means ranged from 63 to 74 percent.

Through the first 11 years after release, the two most severe release treatments (C15+ and D15+) appear to have been successful at keeping oaks alive (fig. 2). Relative to the unreleased control plots, there were 30 percent more oaks in the C15+ plots and 39 percent more oaks in the D15+ plots. However, these differences among treatment means were not statistically significant (p = 0.61).

By the end of the 30^{th} year after release, the four most severe release treatments (C15+, D15+, C20+, and D20+) seemed to have kept more oaks alive than the two least severe treatments (C25+ and D25+), with the number of oaks per acre in the unreleased control plots intermediate between these two groups (fig. 2). Number of oaks ranged from 215 to 226 per acre across the four most severe treatments and from 129 to 145 per acre across the two least severe treatments. However, these differences among treatment means were not statistically significant (p = 0.15).

Basal area per acre--Before application of release treatments, the plantation averaged 4.6 square feet of basal area per acre, in direct-seeded Nuttall oaks only. Plot means ranged from 4.2 to 5.0 square feet per acre, with no significant differences (p = 0.94) among plots at the time of treatment (fig. 3).

As the plantation developed after release, we observed a steady decline over time in the p value associated with statistical significance of differences among treatments in oak basal area per acre, from 0.94 at the time of treatment to 0.24 for 5-year treatment means to 0.11 for 9-year treatment means. This decline in p value indicates that differences among treatments have become larger over time and are approaching the threshold for statistical significance despite high variability in the data. The p value declined to 0.06 by the end of the 11^{th} year after release. The four most severe release treatments clearly produced more oak basal area per acre than did the two least severe treatments or the unreleased control (fig. 3), but these differences were not statistically significant. In fact, the D15+ and D20+ treatment plots contained 49 and 43 square feet of oak basal area per acre, respectively, roughly double the 23 square feet of basal area per acre contained in the unreleased control plots.

Basal area per acre is the only response variable for which statistically significant differences (p = 0.02) were detected among 30-year treatment means (fig. 3). Separation of treatment means revealed a pattern similar to the one observed at the end of the 11^{th} year after release. Specifically, the two most severe deadening treatments (D15+ and D20+) produced oak basal areas of 100 and 105 square feet per acre, respectively, which were significantly greater than the oak basal areas produced by the C25+ and D25+ treatments, 64 and 44 square feet per acre, respectively. In fact, the D20+ release treatment, with a basal area of 105 square feet per acre, was the only treatment that produced a significantly larger oak basal area than the 66 square feet per acre found in the unreleased control plots. However, even though the four most severe release treatments, with oak basal areas ranging from 84 to 105 square feet per acre, appear to have produced larger basal areas than the unreleased control, most comparisons between these treatments and the unreleased control were not statistically significant.

Quadratic mean diameter--Quadratic mean diameter of direct-seeded Nuttall oaks across the plantation at the time the study was established was 1.18 inches. Quadratic mean diameter of treatment plots ranged from 1.10 to 1.29 inches, with no significant differences (p = 0.76) among plots before application of release treatments (fig. 4).

Like the trend observed for basal area per acre, the p value associated with statistical significance of differences among treatments in oak quadratic mean diameter steadily declined as the plantation developed after release, from 0.76 at the time of treatment to 0.26 for 5-year treatment means to 0.10 for 9-year treatment

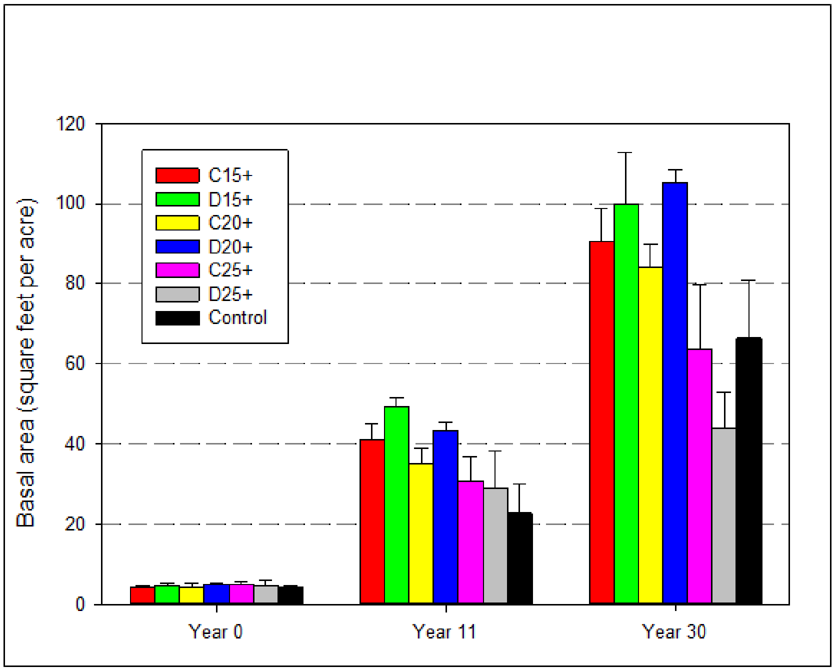

Figure 3--Basal area per acre (± SE) of Nuttall oak, by treatment, immediately before release (year 0) and 11 and 30 years after application of seven release treatments. Means within each year followed by the same letter are not significantly different at the 0.05 level of probability.

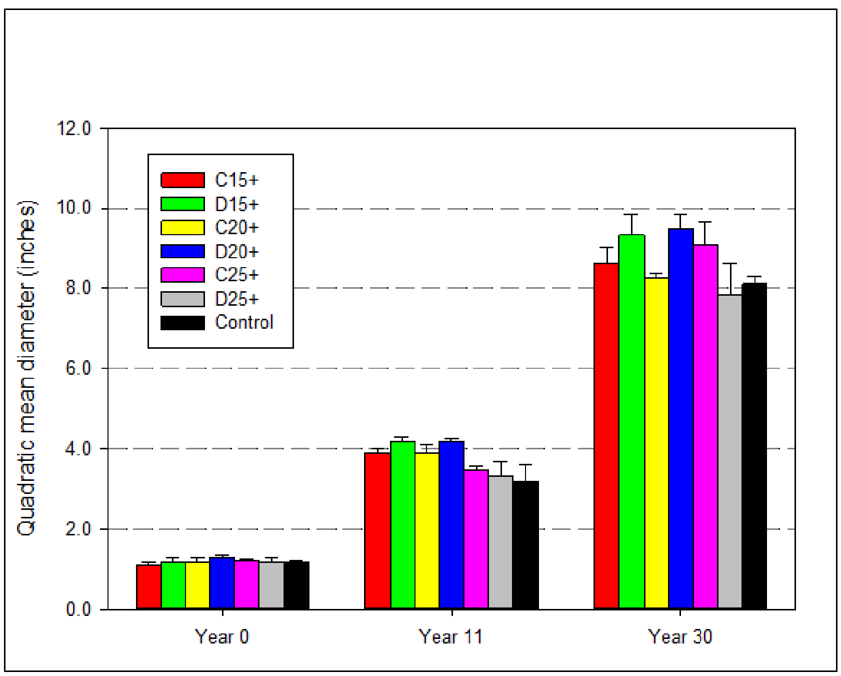

Figure 4--Quadratic mean diameter (± SE) of Nuttall oak, by treatment, immediately before release (year 0) and 11 and 30 years after application of seven release treatments. Means within each year followed by the same letter are not significantly different at the 0.05 level of probability.

means. Again, we believe that this decline in p value indicates that differences among treatments have become larger and are approaching the threshold for statistical significance despite high variability in the data.

The p value reached that threshold at the end of the 11th year after release. In fact, quadratic mean diameter is the only response variable for which statistically significant differences ($p = 0.05$) were found among 11-year treatment means (fig. 4). The two most severe deadening treatments (D15+ and D20+) produced stands with oak quadratic mean diameters of 4.18 and 4.20 inches, respectively, which were significantly larger than the oak quadratic mean diameters found in the D25+ and unreleased control plots, 3.32 and 3.19 inches, respectively. Oak quadratic mean diameters produced through the four most severe release treatments ranged from 3.89 to 4.20 inches and appeared to be larger than those produced through the C25+, D25+, and control treatments, but only some of the comparisons were statistically significant.

However, significant differences in oak quadratic mean diameter among treatments ($p = 0.21$) could not be detected at the end of the 30th year after treatment (fig. 4). All release treatments, except C20+ and D25+, produced stands with oak quadratic mean diameters seemingly larger than the quadratic mean diameter of 8.11 inches found in the unreleased control plots. The magnitude of difference, relative to the control, ranged from 0.52 to 1.38 inches.

Volume per acre--Merchantable volume per acre is perhaps the most important response variable in any evaluation of the effects of silvicultural treatments on timber production. In this study, however, we were unable to detect significant differences among treatments in either oak pulpwood volume per acre ($p = 0.23$) or oak sawtimber volume per acre ($p = 0.48$) at the end of the 30th year after release, even though differences among treatment means appeared to be large.

The D15+ and D20+ release treatments and, to a lesser extent, the C15+ and C20+ treatments, appeared to produce more oak pulpwood volume per acre by the end of the 30th year after release than did the unreleased control or the C25+ and D25+ treatments (fig. 5). Oak pulpwood volumes for the four most severe release treatments ranged from 957 to 1,295 cubic feet per acre, in contrast to only 711 cubic feet per acre in the control plots. However, these differences among treatments were not statistically significant.

Similarly, the D15+ and D20+ treatments appeared to produce more oak sawtimber volume per acre than did any of the other treatments, including the control, 30 years after release (fig. 6). Oak sawtimber volumes for the D15+ and D20+ treatments were 1,785 and 1,435 board feet per acre (Doyle scale), compared to only 661 board feet per acre in the control plots. The D25+ treatment plots contained no oak sawtimber volume at all. These differences among treatments were not statistically significant.

We found much variation among rows within treatments for both of these response variables but particularly in oak sawtimber volume per acre. This large variation within treatments probably thwarted our ability to detect statistically significant differences among treatment means, even though it appears that those differences likely exist.

Free-to-grow oaks per acre--At the time the study was established, there were 283 free-to-grow Nuttall oaks per acre, averaged across all plots. Plot means ranged from 204 to 409 free-to-grow oaks per acre, with no significant differences ($p = 0.22$) among plots before application of release treatments (fig. 7).

By the end of the 11th year after release, there were more free-to-grow oaks per acre in the most severe treatment plots than in the least severe treatment plots and in the unreleased control plots (fig. 7). The number of free-to-grow oaks in the most severe treatment plots ranged from 237 to 328 per acre, with the D15+ and D20+ treatment plots containing the largest number of free-to-grow oaks, 328 and 274 per acre, respectively. The unreleased control plots had only 145 free-to-grow oaks per acre. Free-to-grow oaks in the D15+ and D20+ treatment plots represented 62 and 61 percent of the total number of oaks per acre, respectively, whereas only 36 percent of the oaks in the unreleased control plots were free-to-grow. However, we were unable to detect significant differences ($p = 0.15$) among treatments in the number of free-to-grow oaks per acre.

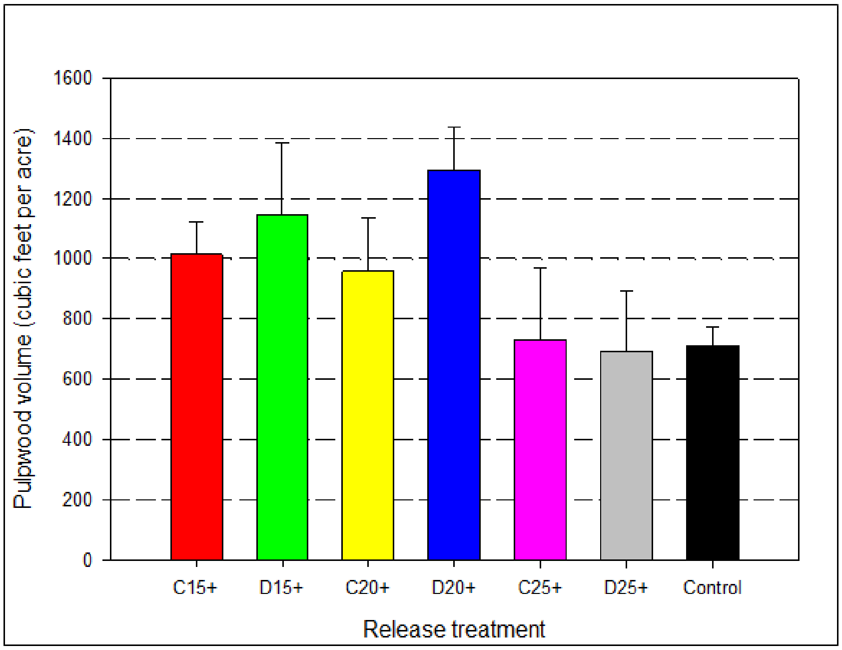

Figure 5--Pulpwood volume per acre (± SE) of Nuttall oak, by treatment, 30 years after application of seven release treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability.

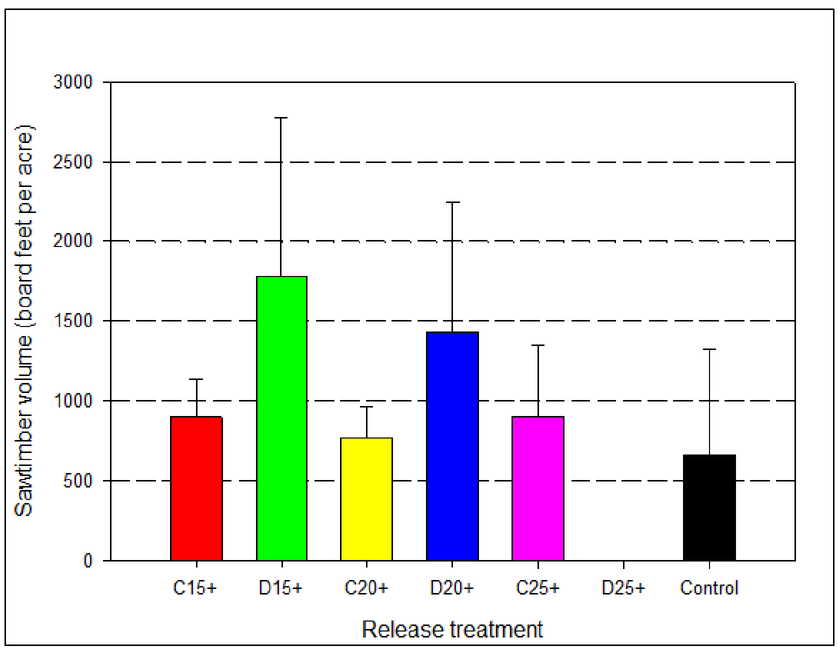

Figure 6--Sawtimber volume per acre (± SE) of Nuttall oak, by treatment, 30 years after application of seven release treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability.

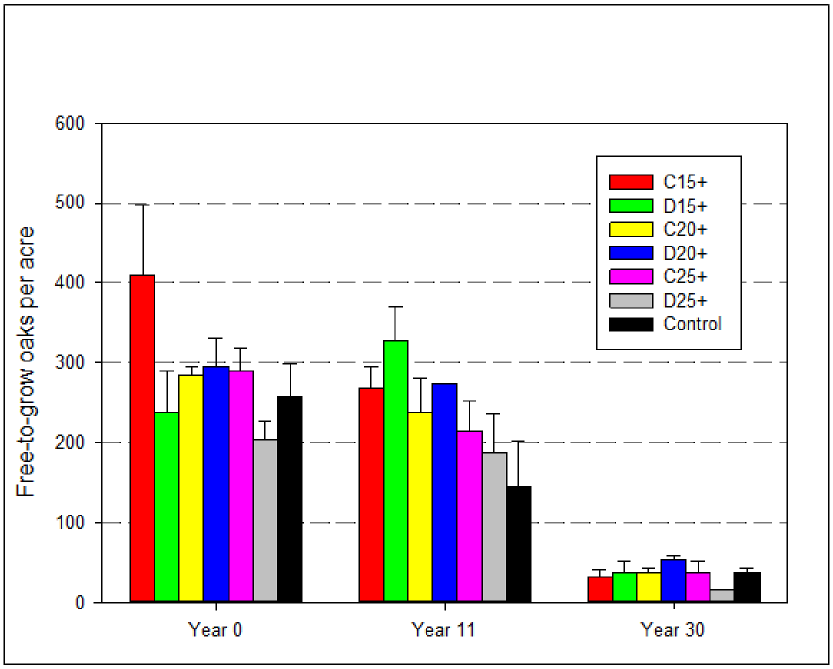

Figure 7--Number of free-to-grow Nuttall oak trees per acre (± SE), by treatment, immediately before release (year 0) and 11 and 30 years after application of seven release treatments. Means within each year followed by the same letter are not significantly different at the 0.05 level of probability.

Between the 11th and 30th years after release, the number of free-to-grow oaks per acre declined drastically across all treatments (fig. 7). There were 32 to 38 free-to-grow oaks per acre 30 years after 5 of the 7 release treatments, including the unreleased control. The D20+ treatment plots averaged 54 free-to-grow oaks per acre, while the D25+ plots averaged only 16 per acre. We found no significant differences ($p = 0.29$) among treatments in the number of free-to-grow oaks per acre.

The drastic decline in the number of free-to-grow oaks per acre across all treatments most likely was due to the destructive effects of the 1994 ice storm. Many oaks across the plantation had small, ragged crowns as a result of severe limb breakage suffered during the storm. Many of these oaks were in a dominant or codominant crown position but were assigned the intermediate crown class due to poor crown condition. Under the general definition that free-to-grow trees receive full sunlight from directly overhead, most of these trees should have been rated as free-to-grow. However, because we used crown class as a surrogate for free-to-grow status, these trees were not rated as free-to-grow. Consequently, the destructive nature of the 1994 ice storm, along with our method of assessment of free-to-grow status, likely resulted in an underestimate of the true number of free-to-grow oaks per acre across all release treatments.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The destructive effects of the 1994 ice storm reduced our ability to detect significant differences among treatments in response to the seven release treatments. It is difficult to determine the effects of a silvicultural operation on tree growth after an ice storm destroys much of the tree’s crown and limits its ability to grow. Even though all trees, including non-oak competitors, were affected, the ice storm may have damaged free-to-grow oaks more severely because they were more exposed to ice accumulation than overtopped oaks and thus more susceptible to crown damage.

Large variation within treatments also likely contributed to our inability to detect significant differences among treatments. Consequently, our statistical analyses revealed significant differences among treatments only for 11-year quadratic mean diameter and 30-year basal area per acre, even though observed differences among treatment means often were quite large.

Despite the lack of a preponderance of statistical evidence to strongly support our view, we are confident that release treatments that removed competitors as tall as the oaks (C15+ and D15+) and 1⅓ times as tall as the oaks (C20+ and D20+) improved long-term growth and development of direct-seeded Nuttall oak saplings. In fact, the moderately severe C20+ and D20+ release treatments are more attractive to landowners because they are as effective but less costly than the more severe C15+ and D15+ release treatments.

Means associated with the D20+ release treatment, in comparison with the other six treatments, consistently ranked at or near the top for all response variables evaluated in this study. In other words, the release treatment that most improved long-term growth and development of direct-seeded Nuttall oak saplings is to deaden all naturally regenerated competitors 1⅓ times as tall or taller than the direct-seeded oaks (D20+).

A comparison of the stand conditions produced 30 years after application of the D20+ release treatment with the stand conditions associated with the unreleased control in this 41-year-old Nuttall oak plantation supports our conclusion. The released stand has 215 oaks per acre, of which 54 are in a free-to-grow position. Oak basal area averages 105 square feet per acre; quadratic mean diameter of these oaks is 9.5 inches. The stand supports 1,295 cubic feet of oak pulpwood per acre and 1,435 board feet (Doyle scale) of oak sawtimber per acre. In contrast, the unreleased stand contains 183 oaks per acre, of which 38 are free-to-grow. Oak basal area is only 66 square feet per acre; quadratic mean diameter is 8.1 inches. The stand has 711 cubic feet of oak pulpwood per acre and 661 board feet (Doyle scale) of oak sawtimber per acre. The released stand contains nearly twice as much oak pulpwood volume and over twice as much oak sawtimber volume as does the unreleased stand.

The released stand is clearly better developed than the unreleased stand. It has a larger oak component than the unreleased stand. Individual oaks are larger and more numerous. Based on the stocking guide for southern bottomland hardwoods developed by Goelz (1995), oak stocking in the released stand is 96 percent, indicative of a fully stocked stand that will need to be thinned in the near future. In contrast, oak stocking in the unreleased stand is only 62 percent, indicative of a less-well-developed stand that must grow another 15 years or so before a thinning is warranted. The released stand has 54 free-to-grow oaks per acre, whereas the unreleased stand has 38 free-to-grow oaks per acre. Clatterbuck and Hodges (1988) suggested that 60 cherrybark oak crop trees per acre are ideal in sawtimber-sized, cherrybark oak-sweetgum stands. The released stand in our study is much closer to this ideal number of oak crop trees per acre than is the unreleased stand. Furthermore, thinning the released stand in the near future likely will increase the number of oak crop trees per acre. In contrast, postponement of thinning for another 15 years in the unreleased stand likely will reduce the number of oak crop trees per acre even further.

The Nuttall oak plantation produced in response to the D20+ release treatment has attained a more advanced stage of development than has the unreleased stand. It is currently more productive and has greater potential for future value growth than the unreleased stand. As such, the released stand is more attractive to landowners interested in production of valuable oak sawtimber.

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