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THIRD-YEAR GROWTH AND BOLE QUALITY RESPONSES TO THINNING IN A RED OAK-SWEETGUM STAND ON A MINOR STREAMBOTTOM SITE IN WEST-CENTRAL ALABAMA[1]

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Abstract-Four thinning treatments were applied to a red oak-sweetgum (*Quercus spp.-Liquidambar styraciflua* L.) stand on a minor streambottom site in west-central Alabama in 1994: (1) unthinned control; (2) light thinning to 70-75 percent residual stocking; (3) heavy thinning to 50-55 percent residual stocking; and (4) B-line thinning to desirable residual stocking for bottomland hardwoods, as recommended by Putnam and others (1960). The thinning operation was a combination of low thinning and improvement cutting to remove most of the pulpwood-sized trees as well as sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Prior to treatment, the stand averaged 196 trees per acre with a basal area of 121 ft^2 per acre. Quadratic mean diameter was 10.7 in., while stocking averaged 107 percent across the 24-acre study area. Light thinning reduced stand density to 63 trees and 62 ft^2 of basal area per acre, increased quadratic mean diameter to 13.5 in., and reduced stocking to 69 percent. Heavy thinning reduced density to 49 trees and 64 ff of basal area per acre, increased quadratic mean diameter to 15.5 in., and reduced stocking to 52 percent. B-line thinning produced stand characteristics intermediate between those resulting from light and heavy thinning. Thinning increased 3- year diameter growth of residual trees, across all species, but there were no significant differences among the three levels of thinning. Thinning also increased diameter growth of codominant trees, but not dominant trees, when averaged across all species. All levels of thinning, except heavy thinning, increased the production of new epicormic branches on the butt log, across all species, but all levels of thinning resulted in fewer than four new branches after 3 years. All levels of thinning increased epicormic branching on sweetgum, but only B-line thinning Increased epicormic branching on red oak and only light thinning increased epicormic branching on hickory (*Carya* spp.). In general, the production of new epicormic branches on the butt log was greatest on low-vigor, lower-crown-class trees.

INTRODUCTION

Thlnning regulates stand density and dramatically increases dlemeter growth of residual trees. Growth of individual trees has been improved in several hardwood forest types such as central upland oaks (Hilt 1979, Sonderman 1984b), Allegheny cherry-maple (*Prunus spp.-Acer* spp.) (Lamson 1985, Lamson and Smith 1988). and mixed Appalachian hardwoods (Lamson and others 1990). In general, the heavier the thinning, the greater the diameter growth response of individual trees. However, very heavy thinning may reduce residual stand density to the point where stand-level basal area growth and volume growth are greatly diminished. Site occupancy is less than optimum because the stand does not fully realize the potential productivity of the site. Recommended minimum residual stocking levels necessary to maintain satisfactory stand-level growth and to ensure full occupancy of the site are 46 to'65 percent in central upland oaks (Hilt 1979) and 45 to 60 percent in cherry-maple stands (Lamson and Smith 1988). Residual stand density equivalent to 52 percent stocking in a young water oak (*Quercus nigra* L.) plantation appeared to be sufficient to promote adequate stand-level basal area growth following thinning, whereas a residual stocking level of 33 percent created a severely understocked stand that will be unable to fully occupy the site for many years to come (Meadows and Goelz, in press).

Degradation of bole quality of residual trees is also sometimes associated with increased thinning intensity. In upland oaks, the number and size of live and dead limbs on the boles of residual trees increased significantly as residual stocking decreased (Sonderman 1984a). On the other hand, Sonderman and Rast (1988) found that the production of epicormic branches on residual oak stems decreased with increasing thinning intensity. The proportion of dominant and codominant trees in the residual stand increases as the intensity of thinning increases. These vigorous, upper-crown-class trees are less likely to produce epicormic branches than are less vigorous, lower-crown-class trees (Meadows 1995). Consequently, a properly designed thinning should improve average bole quality throughout the residual stand. In many stands, however, there may be a trade-off between improved diameter growth and the potential for adverse effects on bole quality of residual trees as thinning intensity increases and residual density decreases.

In most mixed-species hardwood forests, a combination of thinning and improvement cutting is also used to improve species composition of the residual stand (Meadows 1996). In general, the goal is to decrease the proportion of low-value trees and thus increase the proportion of high-value trees, Although most important at the first thinning, improvement of species composition and residual bole quality should also be a major consideration at all subsequent thinnings in mixed-species stands.

These four components of thinning-increased diameter and volume growth of individual trees, increased stand-level basal area and volume growth, maintenance or enhancement of bole quality, and improved species composition-are critically important for the profitable management of hardwood stands for high-quality sawtimber production. Thinning regimes should ideally be designed to optimize value of the stand, thereby synthesizing these four components. However, because maximization of all four components is not likely, some compromises or trade-offs in expected benefits must be accepted.

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Research on thinning in southern bottomland hardwood forests is lacking. General guidelines, such as those recommended by McKnight (1958), Johnson (1981), Meadows (1996), and Goelz and Meadows (1997) are available, but are based more on experience and observation rather than on specific research results. To effectively manage southern bottomland hardwood stands for high-quality sawtimber production, we need quantitative thinning guidelines that include recommendations on: (1) timing of thinning, (2) intensity of thinning, and (3) marking guidelines designed to optimize value of the stand.

This study is the first in a series of thinning studies in red oak-sweetgum stands on minor streambottom sites across the South. The series will consist of at least 12 studies installed over 1 O-1 5 years; all studies in the series will use similar study designs, treatments, and methods. This initial study, as well as all individual studies within the series, was designed to determine the effects of several levels of thinning on: (1) growth and bole quality of individual trees and (2) stand-level growth, development, and yield. The results from the entire series of studies will be combined to: (1) develop practical guidelines for the intermediate management of southern bottomland hardwood stands: (2) evaluate the applicability of several levels of recommended residual stocking across a wide variety of site and stand conditions; and (3) develop a growth and yield model for managed stands of southern bottomland hardwoods.

METHODS

Study Area

The study is located within the floodplain of the Tombigbee River in northeastern Sumter County, near Aliceville, in west-central Alabama. This bottomland tract is near Lake Hollalla and is owned by Gulf States Paper Corporation. The site is subject to flooding during the winter and spring months, but floodwaters generally recede in a few days.

Soils across most of the study site belong to the Ochlockonee series, but there are small areas of Falaya soils in the lower areas. The Ochlockonee soils are well-drained, but the Falaya soils are somewhat poorly drained. Infiltration and permeability rates are moderate to rapid across the site. Both soils have moderate-to-high natural fertility and high available water capacity. Texture in the upper soil horizon across the study area is silt loam to fine sandy loam. Soil pH is very strongly acid and ranges from 4.5 to 5.5 across the site.

The study area is located on a highly productive site suitable for the production of high-quality hardwood sawtimber. Broadfoot (1976) reported average site indexes of the Ochlockonee soils to be 110 ft at 50 years for water oak and 112 ft at 50 years for sweetgum, and estimated site index for cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.) to range from 100 to 120 ft at 50 years. The Falaya soils are only slightly less productive. Site indexes are reported to average 101 ft at 50 years for water oak, 111 ft at 50 years for sweetgum, and 108 ft at 50 years for cherrybark oak (Broadfoot 1976).

The study area is entirely within a 74-acre stand composed primarily of red oak, sweetgum, and hickory. The stand was about 60 years old at the time of study installation and exhibited no evidence of previous harvesting activity. Based on an inventory by company personnel in 1993, sawtimber volume averaged 6,520 bd ft per acre (Doyle scale), of which 81 percent was red oak, and pulpwood volume averaged 12.5 cords per acre (Personal communication. Sam Hopkins. 1993. Research Manager, Gulf States Paper Corporation, P.O. Box 48999, Tuscaloosa, AL 35404). We classified the study area to consist of a small-sawtimber stand on a high-quality site, with high initial stocking.

Plot Design

Plot design followed the recommendations for standard plots for silvicultural research, set forth by the USDA Forest Service Northeastern Forest Experiment Station (Marquis and others 1990). Each individual treatment was uniformly applied across a 2.0-acre, rectangular treatment plot that measured 4 by 5 chains (264 by 330 ft). One 0.6-acre, rectangular measurement plot was established in the center of each treatment plot. Each measurement plot was 2 by 3 chains (132 by 198 ft), providing a l-chain buffer around each. The entire study covered an area of 24 acres.

Treatments

Based on the stocking guide for southern bottomland hardwoods developed by Goelz (1995), we used four levels of residual, stocking as the treatments in this study: (1) an unthinned control: (2) light thinning to 70 to 75 percent residual stocking: (3) heavy thinning to 50 to 55 percent residual stocking; and (4) B-line thinning to desirable residual stocking following partial cutting in well-managed, even-aged southern bottomland hardwoods, as recommended by Putnam and others (1960).

A combination of low thinning and improvement cutting was used to remove most of the pulpwood-sized trees as well as sawtimber-sized trees that were damaged, diseased, of poor bole quality, or of an undesirable species. Modified hardwood tree classes (Meadows 1996, Putnam and others 1960) formed the cutting priority for each treatment. Trees were removed from the cutting stock and cull stock classes first and then from the reserve growing stock class when necessary, until the target residual stocking was met.

Three replications of the four levels of thinning were applied in a randomized complete block design to the 12 treatment plots (experimental units) in September 1994. A contract logging crew directionally felled all trees with a mechanized feller and used rubber-tired skidders to remove the merchantable products in the form of longwood. Most of the material cut was marketed as pulpwood.

Measurements

We conducted a preharvest survey to determine species composition and initial stand density on each 0.8acre measurement plot. We recorded species, diameter at breast height (d.b.h.), crown class, and tree class on all trees greater than or equal to 3.5 in. d.b.h. Based on hardwood tree classes as defined by Putnam and others (1960) and modified by Meadows (1996), we marked the stand for thinning to the target residual stocking prescribed for each treatment. The length and grade of all sawlogs, as defined by Rast and others (1973), and the number of epicormic branches on each 16-h log section were recorded on those trees designated as "leave" trees. We also measured merchantable height, height to the base of the live crown, and total height on a subsample of leave trees. Crown class, d.b.h., and the number of epicormic branches on each 16-ft log section were measured annually for the first 3 years after thinning. First-year responses to the thinning treatments were reported by Meadows and Goelz (1998).

RESULTS AND DISCUSSION

Stand Conditions Prior to Thinning

We found no significant differences among treatment plots In any preharvest characteristics. Prior to thinning, the stand averaged 196 trees and 121 ft^2 of basal area per acre, with a quadratic mean diameter of 10.7 in. The average stocking of 107 percent exceeded the level (100 percent) at which lhinning is recommended in southern bottomland hardwood stands (Goelz 1995). Although the stand was dense, most of the larger, upper-crown-class trees were healthy and exhibited few symptoms of poor vigor, such as crown deterioration, loss of dominance, or the presence of numerous epicormic branches along the boles. Little sunlight reached the forest floor, except in small gaps created by the death of scattered trees throughout the stand. In short, the stand needed thinning but was not stressed to. the point of stagnation at the time of study installation.

The study area was contained within an even-aged, mixed-species stand dominated by red oak, hickory, and eweetgum. Several species of red oaks, principally water, cherrybark, and willow (*Quercus phellos* L.) oaks with lesser smounts of southern red *(Q. falcata* Michx.) and Shumard (*Q. shumardii* Buckl.) oaks, accounted for about 45 percent of the basal area and were found primarily in the upper canopy. Quadratic mean diameter of red oaks was 16.1 in. Shagbark hickory [*Carya ovata* (Mill.) K. Koch] and mockernut hickory [C. *tomentosa* (Poir.) Nutt.] together accounted for about 25 percent of the basal area. Hickories were found primarily in the mid-canopy, but scattered Individuals occurred in the upper canopy. Sweetgum comprised about 12 percent of the basal area and occurred primarily as lower-crown-class trees. Other species scattered throughout the stand included white oak *(Q. alba* L.), overcup oak (Q. *lyrata* Walt.), swamp chestnut oak (Q. *michauxii Nutt.),* green ash (*Fraxinus pennsylvanica* Marsh.), and various elms (*Ulmus* spp.). Along with small hickories and sweetgum, red mulberry (*Morus rubra* L.), American hornbeam (*Carpinus caroliniana* Walt.), and maples dominated the understory.

Stand Development Following Thinning

Light thinning reduced stand density to 83 trees and 82 ft^2 of basal area per acre, increased quadratic mean diameter to 13.5 in., and reduced stocking to 69 percent. It removed 62 percent of the trees and 31 percent of the basal area. Heavy thinning reduced density to 49 trees and 64 ft^2 of basal area per acre, increased quadratic mean diameter to 15.5 in., and reduced stocking to 52 percent. It removed 73 percent of the trees and 43 percent of the basal area. B-line thinning reduced stand density to 65 trees and 86 ft^2 of basal area per acre, increased quadratic mean diameter to 15.6 in., and reduced stocking to 70 percent. It removed 68 percent of the trees and 37 percent of the basal area. B-line thinning was similar to light thinning in terms of basal area and stocking of the residual stand, similar to heavy thinning in quadratic mean diameter of the residual stand, and intermediate between the two in trees per acre contained in the residual stand. All thinning treatments produced stand characteristics significantly different from the unthinned control. Average d.b.h. of trees removed during the logging operation ranged from 7.1 in. in the light thinning treatment to 8.3 in. in the B-line thinning treatment. Overall average d.b.h. of trees removed was 8.0 in.

Thinning also improved species composition of the residual stand. All thinning treatments increased the proportion of red oak and decreased the proportions of both sweetgum and hickory within the residual stand. Most of the sweetgum and hickory removed from the stand were lower-crown-class trees.

Stand conditions did not change significantly during the 3 years following thinning (table 1). A few trees died in all of the plots, except those subjected to heavy thinning where no mortality occurred. Mortality was greatest after B-line thinning (9.2 percent over 3 years), but was similar following light thinning (6.0 percent) and in the unthinned control (6.5 percent). A few trees were destroyed during the logging operation, but most of the mortality occurred as windthrow. These changes in trees per acre were not significantly different among treatments.

Stand-level basal area growth and increases in stocking and quadratic mean diameter, although not significantly different among treatments, indicate that the stand may be recovering faster from heavy thinning and B-line thinning than from light thinning (table 1). We observed small increases in stand-level basal area in the lightly thinned and unthinned stands (2 ft^2 of basal area growth in the 3 years

Table l-Stand conditions and individual tree diameter growth 3 years after application of four thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability

Treatment	Trees	Basal area	Stocking	Quadratic mean diameter	Diameter growth
	No./ac	*Sq ft/ac*	*Percent*	------ *Inch* --------	
Unthinned	172a	119 a	*103* a	11.3 b	*0.24* b
Light thinning	*78* b	*84* bc	*70* b	*14.2* ab	**.46** a
Heavy thinning	49 c	69 c	*56 c*	*16.4* a	**.56** a
B-line thinning	59 bc	90 b	*73* b	*16.7* **a**	**.61 a**

following each treatment). However, larger increases of 5 and 4 ft^2 were found as a result of heavy thinning and B-line thinning, respectively. In fact, basal area growth in the heavily thinned stand was great enough that its total basal area is now statistically similar to the total basal area in the lightly thinned stand, a situation not found 1 year after treatment (Meadows and Goelz 1998). A similar trend was observed for the changes in stocking among the four treatments. All treatments also produced increases in quadratic mean diameter, with heavy thinning and B-line thinning again resulting in the largest increases (0.9 in. and 1.1 in., respectively), as compared to 0.5 in. and 0.7 in. in the unthinned and lightly thinned stands, respectively.

Diameter Growth
For the first time since study installation, we detected significant differences between the thinning treatments and the unthinned control in cumulative diameter growth of individual trees, but there were no differences among the three levels of thinning 3 years after treatment (table 1). Cumulative diameter growth of trees in the thinned stands averaged about 2 to 2.5 times greater than the average diameter growth of trees in the unthinned stand.

Individual species groups varied significantly in their diameter-growth response to the four treatments (fig. 1). Three-year cumulative diameter growth of residual red oaks (primarily water, cherrybark, and willow oaks) in the thinned stands was nearly twice as great as that in the unthinned stand and ranged from 0.83 to 0.86 in. across the three levels of thinning. Thinning also more than doubled diameter growth of residual sweetgum trees, but response was less than that observed among red oaks. Diameter growth of hickory was relatively poor, but the largest increase occurred in response to heavy thinning.

None of the three levels of thinning increased diameter growth of dominant trees, when averaged across all species, but heavy thinning and B-line thinning did increase diameter growth of codominant trees by about 40 to 45 percent (fig. 2). Both the heavy and B-line thinning treatments more than

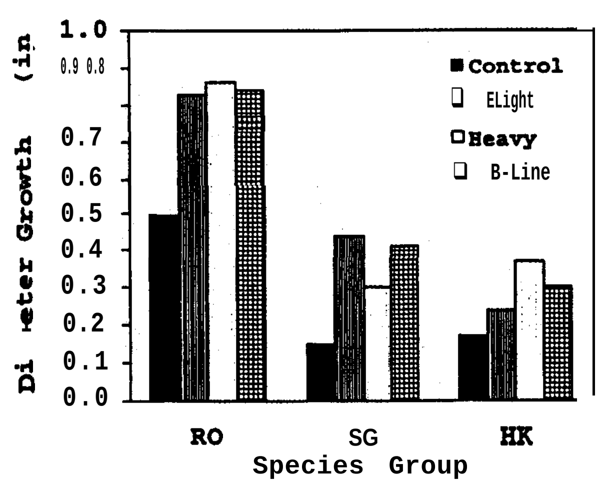

Figure I-Diameter growth of residual trees, by species group, during the first 3 years after application of four thinning treatments (RO = red oak, SG = sweetgum, HK = hickory).

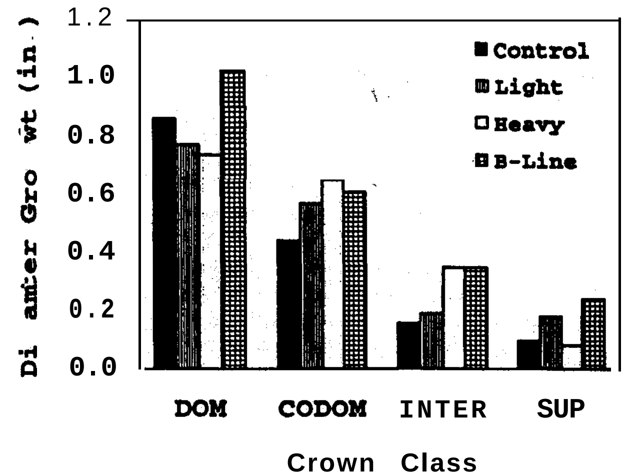

Figure P-Diameter growth of residual trees, by crown class, during the first 3 years after application of four thinning treatments (DOM = dominant, CODOM = codominant, INTER = intermediate. SUP = suppressed).

doubled diameter growth of intermediate trees. Light thinning produced no or only small increases in diameter growth across these three crown classes. Diameter-growth response of suppressed trees was erratic across treatments primarily because thinning removed most of these inferior trees.

It is clear that all three levels of thinning successfully increased diameter growth of residual trees within the first 3 years following thinning. At this time, we are unable to detect any significant differences among these three levels, when compared across all trees, across species groups, or across crown classes. However, heavy thinning and B-line thinning appear to produce the greatest increases in djameter growth, at least in some circumstances. Perhaps differences among the three levels of thinning will become more evident in the future.

Epicormic Branching
Because we removed most of the trees of poor bole quality during the thinning operation, residual trees in the thinned stands, on average, had significantly fewer epicormic branches on the butt log 3 years after thinning than did trees in the unthinned stand (table 2). However, all levels of thinning, except heavy thinning, significantly increased the production of new epicormic branches on the butt log, even though trees in all treatments averaged fewer than four new branches during the first 3 years after thinning. Productton of new epicormic branches varied greatly among individual trees. Some of the high-vigor trees produced no new branches, while many others produced only a few. Low-vigor trees, on the other hand, generally produced many new epicormic branches. Production of new epicormic branches, especially on the butt log, seems to be a delayed consequence of thinning. Meadows and Goelz (1998) reported that trees in all treatments averaged less than one new epicormic branch during the first year after treatment in this study. Our subsequent observations indicate that the majority of new epicormic branches were produced during the second year and that production of new branches during the third year was negligible. However, most new epicorrnic

Table 2-Number of epicormic branches on the butt logs of residual trees 3 years after application of tour thinning treatments. Means followed by the same letter are not significantly different at the 0.05 level of probability

Treatment	Total epicormic branches	New epicormic branches
	Number	- - - - - - -
Unthinned	6.9 a	1.4 b
Light thinning	4.1 b	3.0 a
Heavy thinning	3.2 b	2.1 ab
Wine thinning	5.2 ab	3.5

branches produced during the first and second years survived through the third year.

Among the major species groups, only B-line thinning increased the production of new epicormic branches on the butt logs of red oaks and only light thinning increased epicormic branching in hickories (fig. 3). In contrast, all levels of thinning greatly increased the production of new epicormic branches on the butt logs of sweetgum trees. Because light thinning retained a high proportion of low-vigor trees, epicormic branching on sweetgum following this treatment seemed particularly high. The observation that the majority of these new branches were produced during the rncond year following thinning held true across all three species groups. It is important to note that heavy thinning had no significant effect on the production of new epicormic branches on the butt logs of either red oaks or hickories,

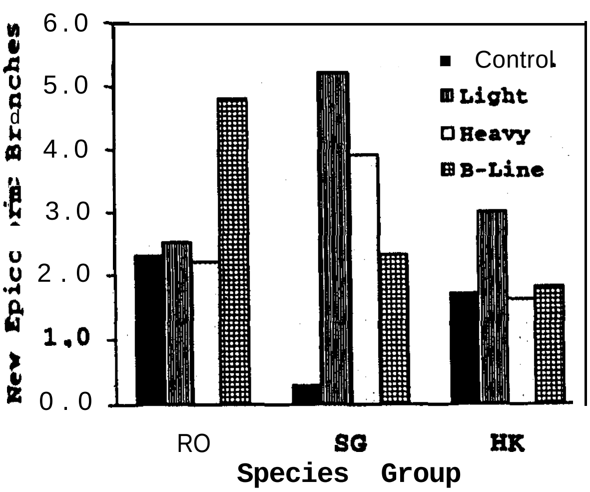

Figure J-Number of new epicormic branches produced on the butt logs of residual trees, by species group, during the first 3 years after application of four thinning treatments (RO = red oak, SG = sweetgum, HK = hickory).

even though Meadows (1995) categorized most bottomland red oaks as highly susceptible to epicormic branching and speculated that hickories were moderately susceptible. Nearly all of the residual red oaks and hickories in the heavily thinned stand were high-vigor, upper-crown-class trees that are generally less likely to produce epicormic branches than are trees in poor health.

Production of new epicormic branches on the butt log also varied among crown classes, across all species (fig. 4). In general, new epicorrnic branches were more frequent on the boles of lower-crown&class trees than on the boles of upper-crown-class trees, especially for trees in the thinned stands. We observed the same trend for the total number of epicormic branches on the butt log (fig. 5). Dramatically more epicormic branches were found on the boles of

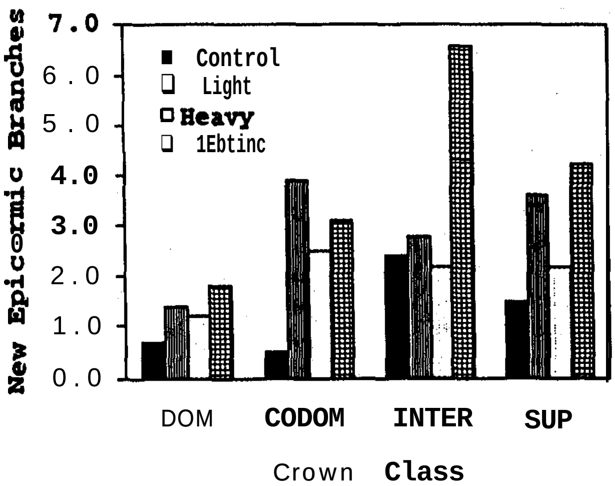

Figure 4—Number of new epicormic branches produced on the butt logs of residual trees, by crown class, during the first 3 years after application of four thinning treatments (DOM = dominant, CODOM = codominant. INTER = intermediate, SUP = suppressed).

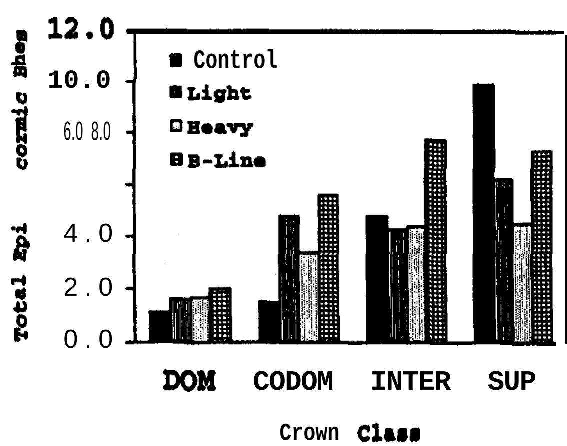

Figure 5—Total number of epicormic branches on the butt logs of residual trees, by crown class, 3 years after application of four thinning treatments (DOM = dominant, CODOM = codomlnant, INTER = intermediate. SUP = suppressed).

intermediate and suppressed trees than on the boles of dominant and codominant trees, even in the unthinned stand. This observation indicates that epicormic branches are often produced in response to increased stress and reduced vigor, even in undisturbed stands.

These results support the hypothesis advanced by Meadows (1995) that the tendency for an individual hardwood tree to produce epicormic branches in response to some disturbance or stress is controlled by the species and initial vigor of the particular tree. Meadows (1995) noted that hardwood species vary greatly in their likelihood to produce epicormic branches and provided a classification of the susceptibility of most bottomland hardwood species to epicormic branching. Meadows (1995) also hypothesized that tree vigor is the mechanism that controls the production of epicormic branches when a tree is subjected to some type of disturbance or stress. It follows, then, that healthy, vigorous trees, even of susceptible species, are much less likely to produce epicormic branches than are trees in poor health. Our observations in this study that epicormic branching varied not only by species but also among crown classes strongly support these hypotheses.

CONCLUSIONS

None of the treatments significantly affected stand-level growth and development. However, the stand appears to be recovering faster from heavy thinning and B-line thinning than from light thinning. Although none of the increases were statistically significant, these two treatments produced greater stand-level basal area growth and greater increases in stocking and quadratic mean diameter, when compared to light thinning and the unthinned control.

Thinning increased diameter growth of residual trees, but there were no significant differences among the three levels of thinning. The greatest diameter-growth response occurred within the red oak group, but all levels of thinning doubled the diameter growth of sweetgum as well. None of the three levels of thinning increased diameter growth of dominant trees, but heavy thinning and B-line thinning increased growth of codominant trees by about 40-45 percent. Light thinning produced only moderate increases in diameter growth of codominant trees.

All levels of thinning, except heavy thinning, significantly increased the production of new epicormic branches on the butt logs of residual trees. However, trees in all treatments averaged fewer than four new branches during the first 3 years after thinning. All levels of thinning increased the production of epicormic branches on sweetgum, but only B-line thinning increased epicormic branching on red oak and only light thinning increased epicormic branching on hickory. In general, the production of new epicormic branches was greatest on low-vigor, lower-crown-class trees.

Although these third-year results are not definitive, it appears that heavy thinning produced the combination of stand density and structure that best promoted rapid stand-level growth and individual-tree diameter growth, with the least adverse effect on epicormic branching and bole quality of residual trees. B-line thinning also promoted rapid stand-level growth and rapid diameter growth of residual trees, but had a more detrimental effect on epicormic branching, particularly of red oaks, that may eventually lead to reductions in both log grade and stand value. Although light thinning increased diameter growth of residual trees, it had little or no effect on stand-level growth and development, and led to large increases in new epicormic branches on both sweetgum and hickory.

Heavy thinning removed nearly all of the small-diameter, low-vigor, lower-crown-class trees, whereas B-line thinning and, to a greater degree, light thinning retained increasingly larger proportions of these inferior trees. Consequently, heavy thinning concentrated diameter growth on large, healthy trees that contributed greatly to stand-level growth and minimized the production of new epicormic branches. Both B-line thinning and light thinning retained sufficient numbers of lower-crown-class trees to impede stand-level growth and to increase the risk of epicormic branching.

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