FOURTH-YEAR EFFECTS OF THINNING ON GROWTH AND EPICORMIC BRANCHING IN A RED OAK-SWEETGUM STAND ON A MINOR STREAMBOTTOM SITE IN WEST-CENTRAL ALABAMA

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Abstract–Four thinning treatments were applied to a 60-year-old, red oak-sweetgum (*Quercus* spp.-*Liquidambar styraciflua* L.) stand on a minor streambottom site in west-central Alabama in late summer 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 consisted of 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 thinning, stand density averaged 196 trees and 121 square feet of basal area per acre. Average stand diameter was 10.7 inches, while stocking averaged 107 percent across the 24-acre study area. Light thinning reduced stand density to 83 trees and 82 square feet of basal area per acre, increased average stand diameter to 13.5 inches, and reduced stocking to 69 percent. Heavy thinning reduced stand density to 49 trees and 64 square feet of basal area per acre, increased average stand diameter to 15.5 inches, and reduced stocking to 52 percent. Putnam's B-line thinning reduced stand density to 65 trees and 86 square feet of basal area per acre, increased average stand diameter to 15.6 inches, and reduced stocking to 70 percent. Only small increases in stand-level basal area and average stand diameter were observed in the thinned areas 4 years after thinning. Thinning significantly increased diameter growth of residual trees, across all species, but there were only slight differences among the three levels of thinning. These increases in diameter growth were most pronounced among red oaks. Thinning produced only small increases in the number of new epicormic branches on the butt logs of residual trees, averaged across all species. Epicormic branching varied widely across both species and crown classes. Thinning had little effect on epicormic branching in red oaks, but greatly increased the production of new epicormic branches in sweetgum. Heavy thinning appears to have produced the best combination of stand-level growth and individual-tree diameter growth, with minimal increases in epicormic branching, especially among red oak crop trees.

INTRODUCTION

Profitable management of hardwood stands for sawtimber production depends not only on maintenance of satisfactory rates of growth, but also on successful development and maintenance of high-quality logs. In general, a combination of thinning and improvement cutting can be used in most mixed-species bottomland hardwood forests to: (1) enhance growth of individual residual trees, (2) improve stand-level growth, (3) maintain and improve bole quality of residual trees, and (4) improve species composition of the stand (Meadows 1996).

Thinning regulates stand density and increases diameter growth of residual trees, as has been reported for several hardwood forest types, such as upland oaks in the Midwest (Hilt 1979, Sonderman 1984b), cherry-maple (*Prunus* spp.-*Acer* spp.) in the Allegheny Mountains (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, even though diameter growth and volume growth of individual residual trees are greatly enhanced. In very heavily thinned stands, site occupancy may be 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 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 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 2001).

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Degradation of bole quality of residual trees is also sometimes associated with increased thinning intensity. For example, the number and size of both living and dead limbs on the boles of residual upland oak 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. In stands thinned from below, 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 well-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 stand density decreases.

A combination of thinning and improvement cutting can also be used to improve species composition of mixed-species hardwood stands (Meadows 1996). In general, the goal is to decrease the proportion of low-value species and thus increase the proportion of high-value species. Although most important at the time of the first thinning, improvement of species composition should be a major consideration whenever a partial cutting is performed in mixed-species hardwood stands.

These four components of thinning, increased diameter and volume growth of individual trees, increased stand-level basal area and volume growth, enhanced bole quality, and improved species composition, are critically important for the profitable management of hardwood stands for high-quality sawtimber production. Ideally, thinning regimes should be designed to optimize the value of the stand, as determined by these four components. However, because maximization of all four components is not possible, some trade-offs in expected benefits must be accepted.

Research on thinning in southern bottomland hardwood forests is lacking. Existing guidelines, such as those recommended by McKnight (1958), Johnson (1981), Meadows (1996), and Goelz and Meadows (1997), are too general and are based more on experience and observation rather than on actual research results. Successful management of southern bottomland hardwood stands for high-quality sawtimber production requires quantitative thinning guidelines that include recommendations on: (1) timing of the first and subsequent thinnings, (2) intensity of thinning, and (3) marking rules designed to optimize stand value throughout the rotation.

To address this need for quantitative thinning guidelines, we are establishing a series of thinning studies in red oak-sweetgum stands on minor streambottom sites across the South. All studies in the series use the same study design, treatments, and methods. The study reported here is the first in the series. All individual studies within the series are designed to determine the effects of several levels of thinning on: (1) stand-level growth, development, and yield, and (2) growth and bole quality of individual trees. Results from the entire series of 10-12 studies will be combined to: (1) develop practical guidelines for the intermediate management of southern bottomland hardwood stands, (2) evaluate the applicability of various 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 the community of Warsaw in west-central Alabama. The land is owned by Gulf States Paper Corporation. The site is subject to periodic flooding during the winter and spring months, but floodwaters generally recede within 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. Broadfoot (1976) reported average site indexes of the Ochlockonee soils to be 110 feet at 50 years for water oak and 112 feet at 50 years for sweetgum, and estimated site index for cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.) to range from 100 to 120 feet at 50 years. The Falaya soils are only slightly less productive. Site indexes are reported to average 101 feet at 50 years for water oak, 111 feet at 50 years for sweetgum, and 108 feet at 50 years for cherrybark oak (Broadfoot 1976).

The study area is located within a 74-acre stand composed primarily of red oak, sweetgum, and hickory (*Carya* spp.). Principal red oak species are cherrybark and water oaks, with scattered trees of willow oak (*Quercus phellos* L.), southern red oak (*Q. falcata* Michx.), and Shumard oak (*Q. shumardii* Buckl.). White oak species include white oak (*Q. alba* L.), overcup oak (*Q. lyrata* Walt.), and swamp chestnut oak (*Q. michauxii* Nutt.). The stand was about 60 years old at the time of study installation. There was no evidence of previous harvesting activity in the stand. Based on an inventory by Company personnel in 1993, sawtimber volume averaged 6,520 board feet 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).

Plot Design

Plot design followed the recommendations for standard plots for silvicultural research, set forth by the U.S. Forest Service's 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 feet). 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 feet), providing a 1-chain buffer around each. The entire study covered an area of 24 acres.

Treatments

Treatments were defined as four levels of residual stocking, based on a stocking guide developed by Goelz (1995) for southern bottomland hardwoods: (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. Hardwood tree classes, as originally defined by Putnam and others (1960) and modified by Meadows (1996), 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 treatments 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 utilized as pulpwood.

Measurements

We conducted a preharvest survey to determine species composition and initial stand density on each 0.6-acre measurement plot. We recorded species, diameter at breast height (dbh), crown class, and tree class on all trees greater than or equal to 3.5 inches dbh. Based on hardwood tree classes, 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-foot log section were recorded on those trees designated as “leave” trees. We also measured sawtimber merchantable height, height to the base of the live crown, and total height on a subsample of “leave” trees. Crown class, dbh, and the number of epicormic branches on each 16-foot log section were measured annually for the first 4 years after thinning. Previous results were reported by Meadows and Goelz (1998, 1999).

RESULTS AND DISCUSSION

Stand Conditions Prior to Thinning

Prior to thinning, the stand averaged 196 trees and 121 square feet of basal area per acre, with a quadratic mean diameter of 10.7 inches. The average stocking of 107 percent exceeded the level (100 percent) at which thinning is recommended in southern bottomland hardwood stands (Goelz 1995). We found no significant differences among treatment plots in any preharvest characteristics. Although the stand was dense, most of the 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. The stand needed thinning but was not stressed to the point of stagnation at the time of study installation.

This even-aged, mixed-species stand was dominated by red oak, hickory, and sweetgum. Red oaks (primarily cherrybark and water oaks, but with lesser numbers of willow, southern red, and Shumard oaks) accounted for about 45 percent of the basal area of the preharvest stand. Red oaks dominated the upper canopy and had a quadratic mean diameter of 16.1 inches. Mockernut hickory [*Carya tomentosa* (Poir.) Nutt.] and shagbark hickory [*C. ovata* (Mill.) K. Koch] 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 made up about 12 percent of the basal area and occurred primarily as lower-crown-class trees. Other species scattered throughout the stand included white, overcup, and swamp chestnut oaks, green ash (*Fraxinus pennsylvanica* Marsh.), American elm (*Ulmus americana* L.), and winged elm (*U. alata* Michx.). Along with small hickories and sweetgum, American hornbeam (*Carpinus caroliniana* Walt.), red mulberry (*Morus rubra* L.), black tupelo (*Nyssa sylvatica* Marsh.), and various maples dominated the understory.

Table 1—Stand conditions and individual-tree diameter growth 4 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	Mortality	Basal area	Basal area growth	Stocking	Quadratic mean diameter	Cumulative diameter growth
	No./acre	Pct	Sq ft/acre	Sq ft/acre	Pct	In.	In.
Unthinned	169 a	8.2 a	121 a	4 ab	105 a	11.4 b	0.33 c
Light thinning	78 b	6.0 a	85 bc	3 b	70 b	14.3 ab	0.58 b
Heavy thinning	49 c	0.0 a	70 c	6 a	57 c	16.6 a	0.69 ab
B-line thinning	59 bc	9.2 a	91 b	5 ab	74 b	16.9 a	0.78 a

Table 2—Total number and number of new epicormic branches on the butt logs and on upper logs of residual trees 4 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	---------------*Butt logs*---------------		--------------*Upper logs*-------------	
	Total epicormic branches	New epicormic branches	Total epicormic branches	New epicormic branches
Unthinned	6.7 a	1.1 b	15.1 a	4.0 a
Light thinning	4.2 a	3.1 a	16.5 a	7.8 a
Heavy thinning	3.8 a	2.7 a	13.8 a	6.5 a
B-line thinning	4.8 a	3.1 a	14.6 a	7.3 a

Stand Development Following Thinning

Light thinning reduced stand density to 83 trees and 82 square feet of basal area per acre, increased quadratic mean diameter to 13.5 inches, 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 square feet of basal area per acre, increased quadratic mean diameter to 15.5 inches, 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 square feet of basal area per acre, increased quadratic mean diameter to 15.6 inches, and reduced stocking to 70 percent. It removed 68 percent of the trees and 37 percent of the basal area. All thinning treatments produced stand characteristics significantly different from the unthinned control. Average dbh of trees removed during the logging operation ranged from 7.1 inches in the light thinning treatment to 8.3 inches in the B-line thinning treatment. Overall average dbh of trees removed was 8.0 inches.

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 and were utilized as pulpwood.

During the 4 years following thinning, we observed a small amount of mortality in all of the plots, except those subjected to heavy thinning (table 1). Most of the mortality occurred as a result of windthrow. These decreases in the number of trees per acre during the 4 years following thinning were not significantly different among treatments.

Stand-level basal area growth and increases in stocking and quadratic mean diameter indicate that the stand may be recovering faster from heavy thinning and B-line thinning than from light thinning (table 1). We measured only small increases in stand-level basal area in the lightly thinned and unthinned stands during the 4 years following thinning. However, larger increases in basal area were found as a result of heavy thinning and B-line thinning. In fact, cumulative basal area growth in the heavily thinned stand was significantly greater than cumulative basal area growth in the lightly thinned stand, such that there is no longer a statistical difference between these two treatments in total basal area 4 years after thinning, a situation not found in earlier measurements (Meadows and Goelz 1998). A similar trend was observed for changes in stocking percent among the four treatments (table 1), but these increases were not statistically significant 4 years after thinning. All treatments also produced increases in quadratic mean diameter (table 1), with heavy thinning and B-line thinning again resulting in the largest increases (1.1 inches and 1.3 inches, respectively), as compared to 0.6 inches and 0.8 inches in the unthinned and lightly thinned stands, respectively. Although these results follow the same trend as that observed for stand-level basal area growth, these increases in quadratic mean diameter did not differ significantly among the four treatments.

Diameter Growth

We found significant differences between all three of the thinning treatments and the unthinned control in cumulative diameter growth of individual trees 4 years after treatment (table 1). Depending upon treatment, thinning increased diameter growth of residual trees by 76 to 136 percent when compared to the unthinned control. For the first time since study installation, we also detected differences among the three levels of thinning. Cumulative diameter growth of residual trees 4 years following B-line thinning was

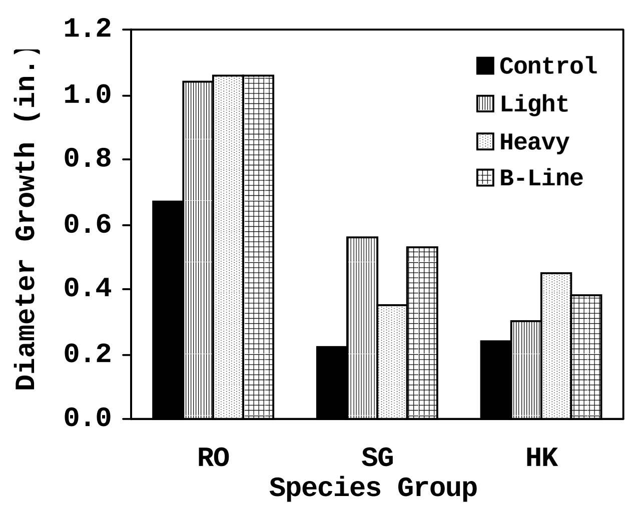

Figure 1–Diameter growth of residual trees, by species group, during the first 4 years after application of four thinning treatments (RO=red oak, SG=sweetgum, HK=hickory).

significantly greater than diameter growth of residual trees following light thinning. As the study continues, we expect to find even greater differences among the three levels of thinning.

Individual species groups varied significantly in their diameter growth response to the four treatments (figure 1). All three levels of thinning increased cumulative diameter growth of residual red oaks by about 55 percent after 4 years (a little more than 1.0 inches as compared to about 0.7 inches for red oaks in the unthinned control). All three thinning treatments also greatly increased cumulative diameter growth of residual sweetgum trees, but response was less than that observed among red oaks. Cumulative diameter growth of hickory was relatively poor, but the largest increases occurred in response to heavy thinning and B-line thinning.

None of the three levels of thinning significantly affected cumulative diameter growth of dominant trees, when averaged across all species, but heavy thinning and B-line thinning increased cumulative diameter growth of codominant trees by about 33 percent over the unthinned control (figure 2). Both the heavy and B-line thinning treatments also nearly doubled cumulative diameter growth of trees in the intermediate crown class. Light thinning failed to produce significant increases in cumulative diameter growth of trees in any of these three crown classes. Cumulative diameter growth response of suppressed trees 4 years after thinning was erratic across treatments primarily because thinning removed most of these small inferior trees.

It is clear that all three levels of thinning successfully increased cumulative diameter growth of residual trees 4 years after thinning. The largest increases in diameter growth as a result of thinning were observed among red oaks in the codominant crown class. In most situations, codominant red oaks were classified as crop trees and were considered to be the most desirable trees for high-quality sawtimber production. Our thinning guidelines were designed to favor these trees and, at least so far, we appear to have been successful in enhancing the diameter growth of the most desirable trees in the stand.

Epicormic Branching

The production of epicormic branches along the merchantable boles of residual trees can be a serious problem in thinning hardwood stands. These epicormic branches cause defects in the underlying wood and can reduce both log grade and subsequent lumber value.

Because we removed most of the trees of poor bole quality during the thinning operation, residual trees in the thinned plots, on average, had fewer epicormic branches on the butt log 4 years after thinning than did trees in the unthinned control, but these differences were not statistically significant (table 2). However, all levels of thinning significantly increased the production of new epicormic branches on the butt log, even though trees in all thinning treatments averaged only about three new branches during the first 4 years after thinning. Epicormic branching on upper logs was uniformly high, regardless of treatment (table 2). Production 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 and fourth years was negligible. However, most new epicormic branches produced during the first 3 years survived through the fourth year.

Wide variation was found among species groups in the number of new epicormic branches produced on the butt log during the 4 years following thinning (figure 3). For

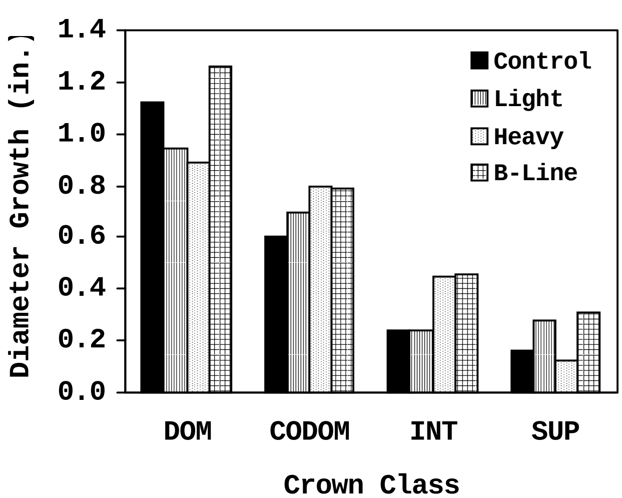

Figure 2–Diameter growth of residual trees, by crown class, during the first 4 years after application of four thinning treatments (DOM=dominant, CODOM=codominant, INT=intermediate, SUP=suppressed).

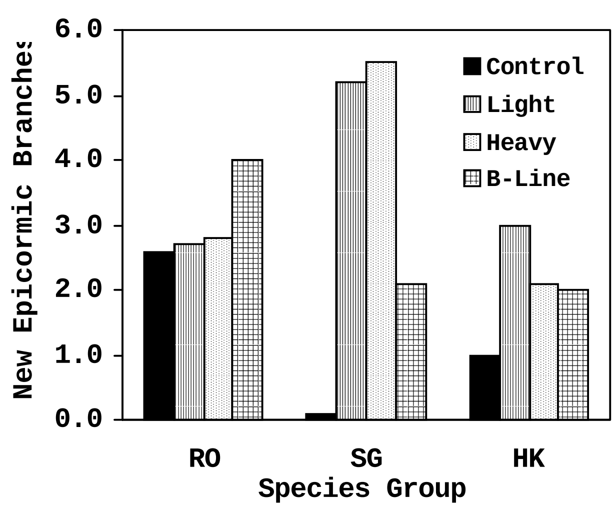

Figure 3–Number of new epicormic branches produced on the butt logs of residual trees, by species group, during the first 4 years after application of four thinning treatments (RO=red oak, SG=sweetgum, HK=hickory).

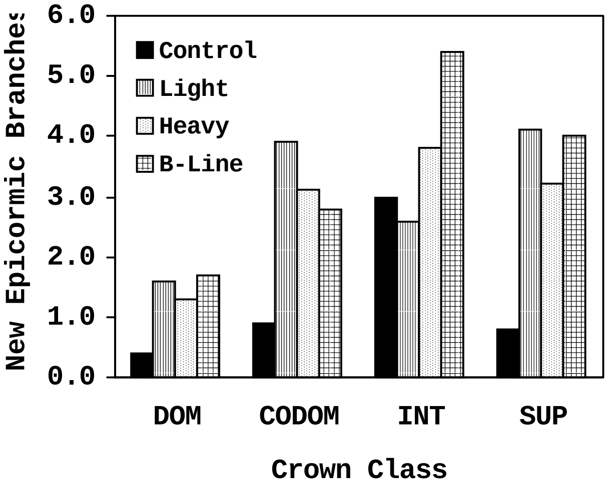

Figure 4–Number of new epicormic branches produced on the butt logs of residual trees, by crown class, during the first 4 years after application of four thinning treatments (DOM=dominant, CODOM=codominant, INT=intermediate, SUP=suppressed).

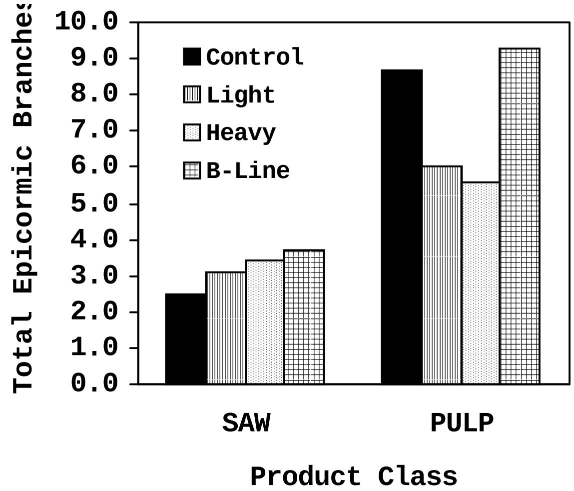

Figure 5–Total number of epicormic branches on the butt logs of residual trees, by product class, 4 years after application of four thinning treatments (SAW=sawtimber, PULP=pulpwood).

example, only B-line thinning increased the production of new epicormic branches on the butt logs of red oaks. In contrast, all levels of thinning greatly increased the production of new epicormic branches on the butt logs of sweetgum trees and more than doubled the number of new epicormic branches on the butt logs of hickories. The observation that the majority of these new branches were produced during the second 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 red oaks, even though Meadows (1995) categorized most bottomland red oaks as highly susceptible to epicormic branching. Nearly all of the residual red oaks 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 (figure 4). In general, new epicormic 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. 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.

When assessing the effects of thinning on epicormic branching, the most important consideration, however, is the total number of epicormic branches found on the butt logs of the crop trees; these are the trees that are favored during the thinning operation and are most likely to produce high-quality sawtimber. Sawtimber trees in the thinned plots averaged 0.6 to 1.2 more epicormic branches on the butt log than sawtimber trees in the unthinned control, when averaged across all species (figure 5). However, these slight increases were not statistically significant. Both light thinning and heavy thinning actually significantly reduced the average number of epicormic branches on the butt logs of pulpwood trees. This reduction may be misleading because we removed most of the pulpwood trees of poor bole quality during the thinning operation.

To carry the analysis one step further, none of the three levels of thinning had a significant effect on the total number of epicormic branches on the butt logs of red oak sawtimber trees 4 years after thinning (figure 6). Red oak sawtimber trees, regardless of treatment, averaged fewer than five epicormic branches on the butt log, generally not enough to result in a reduction in log grade. Sawtimber-sized red oak trees with healthy dominant or codominant crowns apparently are not very susceptible to the production of new epicormic branches following even heavy thinning.

CONCLUSIONS

Stand-level growth and recovery appear to have been somewhat faster after heavy thinning and B-line thinning than after light thinning. In fact, cumulative basal area growth in the heavily thinned stand is now significantly greater than cumulative basal area growth in the lightly thinned stand, such that there is no longer a statistical difference between these two treatments in total basal area 4 years after thinning. Similar, but not statistically significant,

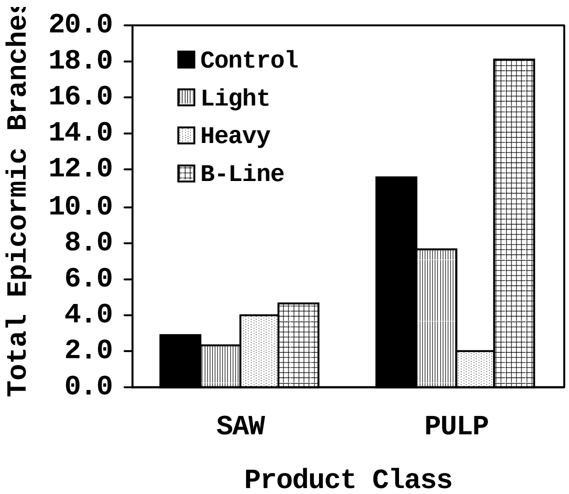

Figure 6–Total number of epicormic branches on the butt logs of red oak residual trees, by product class, 4 years after application of four thinning treatments (SAW=sawtimber, PULP=pulpwood).

increases in both stocking and quadratic mean diameter were observed after both heavy thinning and B-line thinning when compared to light thinning and the unthinned control. Thinning increased diameter growth of residual trees, across all species, but there were only slight differences among the three levels of thinning. Diameter growth response to thinning varied among species groups, with the most pronounced effect observed in red oaks. In fact, all levels of thinning increased cumulative diameter growth of residual red oaks by about 55-58 percent. None of the thinning treatments increased diameter growth of dominant trees, but heavy thinning and B-line thinning increased growth of codominant trees by about 33 percent.

All levels of thinning increased the production of new epicormic branches on the butt logs of residual trees, when averaged across all species, but these increases were relatively small. Thinning had little effect on epicormic branching in red oaks, but greatly increased the production of new epicormic branches in sweetgum. In fact, sawtimber-sized red oaks averaged fewer than five epicormic branches on the butt log 4 years after thinning. This level of epicormic branching is generally not enough to cause a reduction in log grade.

It appears at this time that heavy thinning created a combination of stand density and structure that best promoted rapid stand-level growth and rapid individual-tree diameter growth, with minimal adverse effects on epicormic branching and bole quality of residual trees, especially among red oak crop trees. Heavy thinning removed nearly all of the small-diameter, low-vigor, lower-crown-class trees, whereas the other levels of thinning retained 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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