DIAMETER-GROWTH AND EPICORMIC BRANCHING RESPONSE OF AN EAST TEXAS BOTTOMLAND RED OAK STAND 3 YEARS AFTER THINNING AND FERTILIZATION

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Abstract—To determine the effects of intermediate silvicultural treatments on bottomland hardwoods, two types of thinning (crown thinning and low thinning) and one level of fertilizer (200 pounds per acre N + 50 pounds per acre P) were applied to a predominantly red oak stand in southeastern Texas. Treatments were applied in a 3 by 2 factorial arrangement as a randomized complete block design of 12 acres in size. Crop trees were selected prior to the treatments, and diameter at breast height measurements were taken pretreatment and for 3 proceeding years to assess diameter-growth response of all trees. Epicormic branching measurements were also taken for 3 years posttreatment to evaluate epicormic branching response of all crop trees to crown thinning, low thinning and fertilization. First-year results showed no significant difference in current annual increment (CAI) of crop-tree diameter-growth response; however, second-year results of CAI diameter growth showed that crop trees in thinned plots achieved significantly more growth than in unthinned plots. With third-year results of CAI diameter growth, crop trees in crown-thinned plots grew significantly better than in both low-thinned and unthinned plots, all regardless of fertilization. Epicormic branching was generally greater in crown-thinned and fertilized plots immediately following treatment.

INTRODUCTION

Bottomland hardwood forests occur mainly on floodplain sites of recent alluvium; however, other nonalluvial wet sites can support many of the same hardwood species (Hodges 1994). Alluvial floodplains themselves occur along most streams within the United States, but they are most common and most extensive in the Atlantic Coastal Plain, east Gulf Coastal Plain, Mississippi River Alluvial Plain, and west Gulf Coastal Plain (Hodges 1997). Approximately 30 million acres of bottomland hardwood forests remained in the Southeastern United States in 1994, which is less than one-half of such acreage present at the time of European settlement (Hodges 1994). Much of this acreage reduction was a result of conversion to agricultural use within the Mississippi River Alluvial Plain. Currently there are 214 million acres of forested land in the Southeast (Wear and Greis 2002). Of that, more than 32 million acres are considered forested wetlands including bottomland hardwood forests. Furthermore, according to Hodges and Switzer (1979), most bottomland areas are potentially very productive; however, they are growing below their potential due to the past practices of high grading and lack of effective management. This statement could be made about current hardwood forests as well (Allen and others 2001, Devall and others 2001, Stanturf and others 2001).

One of the cornerstones of silviculture is thinning, which can be defined as any cutting made in an immature stand to stimulate the growth of residual trees as well as to redistribute stand growth by utilizing potential mortality (Hawley and Smith 1954). This research project is concerned with two types of thinning: crown thinning and low thinning. Crown thinning (also known as high thinning or thinning from above) involves removing trees from upper crown classes to favor development of the best trees of the same crown classes (Smith and others 1997). Low thinning (also known as German thinning or thinning from below) is aimed at anticipating mortality and salvaging yield (Daniel and others 1979). This method involves removing trees from the lower crown classes to speed up the natural process of self-thinning (Smith and others 1997).

Fertilization can often be a difficult tool to understand in forest management and is rarely used in hardwood silviculture. Sometimes fertilization will favor strong trees so that it will hasten suppression of weaker trees (Smith and others 1997). There may even be cases, with soils extremely deficient in nutrients, where fertilization must be coupled with thinning to produce any effect. The following concentrations of nitrogen (N), phosphorous (P), and potassium (K) are considered adequate in most higher plants (gymnosperms and angiosperms): 15,000 mg per kg (N), 2,000 mg per kg (P), and 10,000 mg per kg (K) in dry plant tissue (Salisbury and Ross 1992). However, Stone (1977) found growth in young even-aged stands is more limited by competition between trees than by availability of N, P, or K, on well-drained soils with site indices of 60 or better.

In a publication intended to inform private landowners about bottomland forest management, the Louisiana Department of Agriculture and Forestry (LDAF; 1995) advocated low thinning to "leave the largest, most desirable trees to provide seeds . . . [and] eventually raise the quality of the whole forest." They may leave crown thinning out of their prescription because of the general landowner's temptation to high-grade during a crown thinning. In keeping with LDAF (1995), Allen and others (2001) also proposed low thinning as the best intermediate bottomland hardwood thinning treatment. They supported this statement by saying healthy trees generally require a live crown to total height

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ratio of 40 percent or greater, and trees below this proportion are most likely in subordinate crown positions. In a similar publication intended for general hardwood management in Canada, Robertson and others (1991) advocated crown thinning but specifically warned against highgrading of timber stands; they did not discuss low thinning as an option. It is clear there are differing philosophies related to thinning in general as well as thinning in hardwood forests. Therefore, the objectives of the present study are to determine the effects of crown thinning, low thinning, and fertilization on crop tree diameter growth and epicormic branching in an east Texas bottomland red oak stand.

MATERIALS AND METHODS

Study Site

The bottomland red oak stand in this study is located in Angelina County, TX. It is situated in eastern Texas in the western gulf section of coastal plains and flatwoods within the Outer Costal Plain Mixed Forest Province (Keys and others 1995). The major forest type of this area is southern pine with mixed hardwoods. The study area is located on both sides of the Shawnee Creek floodplain, which drains into the Neches River. Shawnee Creek can be described as a minor bottom according to the definition of Hodges and Switzer (1979). The closest incorporated town to the study area is Zavalla, TX. The land is currently owned by Temple-Inland Corporation of Diboll, TX, and is leased to Wolf Creek Hunting Club of Zavalla, TX.

Soils found on the study site are of the Pophers Series, which are classified as fine-silty, siliceous, acid, thermic Aeric Fluvaquents (Dolezel 1988). These soils are somewhat poorly drained and slowly permeable. Due to a slope of less than 1 percent, runoff is slow. This soil overflows two to three times per year in most years, and flooding lasts for several days. The water table is at or near the surface during the cool season, and due to frequent flooding and extended wetness, pine seedlings should not be planted on this type of soil. Pophers soil is used almost entirely as woodland and is well suited for production of quality hardwoods such as water oak (*Quercus nigra* L.), willow oak (*Quercus phellos* L.), and swamp chestnut oak (*Quercus michauxii* Nutt.) (Dolezel 1988). This was proven by estimating site index (base age 50 years) to be 90 to 95 for cherrybark oak (*Quercus pagoda* Raf.), water oak, and willow oak, using the method suggested by Baker and Broadfoot (1979).

History, Climate, and Forest Cover Type

The site was originally intended for regeneration of a loblolly pine (*Pinus taeda* L.) plantation (Personal Communication. Matthew Lowe, Research Forester, Temple-Inland Forest Products Corporation, P.O. Drawer N, Diboll, Texas 75941). It was mechanically prepared by shearing, and herbicides were not used. However, soon after the seedlings were planted, circa 1970, flooding resulted in high seedling mortality. A decision was then made to allow the area to naturally revert to an even-aged bottomland hardwood stand.

Historic records of climate data show the growing season in Angelina County averages 244 days with the last freeze in the spring occurring around March 14 and the first freeze in the fall occurring around November 13 (Griffiths and others 1987). Winters tend to be mild with about 35 days where the temperature falls below 32 °F, and summers tend to be hot and humid with about 103 days where the temperature rises above 90 °F. The average annual daily maximum and minimum temperatures are 78 °F and 56 °F, respectively, and the mean annual precipitation is 41.5 inches, including about 65 days with 0.1 inches or more of precipitation (Griffiths and others 1987). According to Eyre (1980) the majority of this stand can be classified as the willow oak—water oak—diamond leaf (laurel) oak (*Quercus laurifolia* Michx.) (88) forest cover type, which is commonly described as a "pin oak flat." Another important forest cover type that forms a component of the stand is the swamp chestnut oak—cherrybark oak (91) forest cover type (Eyre 1980). This is important to note because the statistical block design was applied in relation to where these specific forest cover types occurred on the landscape.

Experimental Design and Treatment Application

The study area included four replications (blocks). Each block was about 3 acres in size. Within each 3-acre block, there were six 0.5-acre, rectangular treatment plots. Within each 0.5-acre treatment plot, there was a 0.25-acre rectangular measurement plot surrounded by a 15-foot buffer strip, which was installed to limit the spread of fertilizer between measurement plots. The factorial arrangement of treatments for each of the 0.5-acre treatment plots is listed as follows: (1) crown-thinned and fertilized, (2) crown-thinned and unfertilized, (3) low-thinned and fertilized, (4) low-thinned and unfertilized, (5) unthinned and fertilized, and (6) unthinned and unfertilized (control). All were assigned randomly to each of the six treatment plots within each of the four blocks. The study was established in 1998 and pretreatment measurements were taken.

The selection of crop trees was accomplished using crown size, stem position, and crown classification. The crop-tree method was chosen because there is a need to place more attention on individual trees within bottomland hardwood stands. Smith and Long (2001) stated that culmination of stand-level production invariably precedes, sometimes by decades, culmination of individual tree production. Furthermore, according to Stringer and others (1988), the crop-tree approach concentrates treatment benefits from intermediate treatments on trees with the highest potential to increase in value; in area-wide thinnings, trees are more likely to be removed without considering benefits to the residual stand.

When using the crop-tree method, Houston and others (1995) stated that a list of acceptable tree species and stem-quality classes must first be created. The tree-class system suggested in Meadows (1996) was used in selecting crop trees for the study, and the Kraft Crown Classification Method lists four crown positions: dominant, codominant, intermediate, and overtopped (suppressed). Crop-tree selection was limited to trees of the codominant or dominant crown classes in relation to spacing. Meadows and others (2001) stated that the four factors ultimately contributing to crown classification are amount of direct sunlight received from above, amount of direct sunlight received from the sides, crown balance, and relative crown size. When the trees were marked in February 1999, ideas relating to the development of Meadows and others (2001) were well known and used in the selection of crop trees. All red oak trees that exhibited healthy crowns, exhibited or had the potential to develop a grade 1 butt log (Kenna 1981), had few to no epicormic branches on the butt log, and were free of disease were considered suitable crop trees. Other species were selected as crop trees when no suitable red oak species existed; this was done to uphold the thinning method applied and to maintain proper spacing.

Species favored for crop-tree selection were ranked as follows: (1) cherrybark oak, (2) water oak, (3) willow oak, (4) green ash, and (5) sweetgum. Crop trees were selected in the control plots as well as the treated plots. As previously defined, crown thinning consisted of removing trees from the dominant and codominant crown classes while leaving all trees within the intermediate and suppressed classes. During low thinning, only trees from the intermediate and suppressed crown classes were removed. When marking the stand for harvest, trees within the buffer strip were considered competition and recognized as pseudo-crop trees even though they were not measured as part of this study. This was done so that the observations in each measurement plot would not be biased and would be in keeping with the applied silvicultural treatments of crown and low thinning that were applied in early March 1999. During thinning treatments, trees were felled by chainsaw and left in place because of wet soil conditions.

Following the thinning treatments, a single application of granulated fertilizer yielding both nitrogen and phosphorous nutrients was applied to each of the plots randomly selected to receive fertilizer. The fertilization treatment was based on standard fertilization practices used in loblolly pine silviculture (Jokela and Stearns-Smith 1993) and is similar to fertilizer treatments used in upland hardwoods by Graney and Pope (1978). N was applied at the rate of 200 pounds per acre, and P was applied at the rate of 50 pounds per acre as ammonium nitrate (34-0-0) and diammonium phosphate (18-46-0), respectively. Hand-spreaders were used to apply the fertilizer in late June 1999, later than originally planned, due to early spring flooding at the study site.

Measurements

Prior to harvest, all trees within each 0.25-acre measurement plot were described as follows: (1) species; (2) d.b.h. (diameter at breast height, 4.5 feet above ground) of all trees > 3.5 inches (to the nearest 0.1 inch); (3) distance in feet from each tree center to plot center (recorded per 0.1 foot); (4) azimuth of each tree in relation to plot center; and (5) crown classification. Pretreatment measurements were taken in the winter of 1998-99. First-year measurements (after treatment) of tree d.b.h. were collected in December 1999. Second-year measurements of tree d.b.h. were taken in December 2000. Third-year measurements of tree d.b.h. were taken in December 2001.

Epicormic branching was also measured on each crop tree within each of the 24 measurement plots. It was measured from 0 to 17.5 feet high on the tree bole to assess butt log quality. All epicormic branches were categorized as < 1 foot or > 1 foot in length to assess the importance of log defect. This takes into account the fact that older, more established branches are a greater threat to log quality. All branches were tallied by length within each 1-foot height increment separately; they were also broken into two categories within each 1-foot height increment: > 1 foot (old) and < 1 foot (new). First-year epicormic data were collected to assess the 1999 growing season, second-year measurements were taken to assess the 2000 growing season, and third-year measurements were taken to assess the 2001 growing season. However, preharvest measurements of epicormic branching were not recorded.

Analyses

All statistical analyses were done with SAS Version 8 (SAS Institute 2000). The measurement unit was each tree, the experimental unit was each plot, and the sampling unit was the stand itself. Furthermore, this study was analyzed using a randomized complete block design. This was done appropriately through analysis of variance (ANOVA) with 3 degrees of freedom for blocking, 5 degrees of freedom for treatments, and 15 degrees of freedom for error, which makes 23 degrees of freedom total. Significant differences were reported through ANOVA when $p \leq 0.1$ in the initial F-test. Comparison between each of the separate treatments was analyzed using the Least Significant Difference (LSD) multiple pairwise comparison method.

Specifically, periodic annual increment (PAI) of mean diameter growth in 1999, 2000, and 2001 was evaluated through ANOVA to show the progression of cumulative growth according to treatment. For example, PAI in 2001 was calculated by taking each tree's diameter measurement in 2001 (x_3), subtracting each tree's pre-treatment diameter measurement (x_{pre}), and then dividing that quantity by 3 to represent the period (third-year) that the measurement was taken: $(x_3 - x_{pre})/3$. For the final step in figuring PAI, the value for each tree was then totaled to calculate the periodic mean growth. Then, current annual increment (CAI) of mean diameter growth was evaluated each year using a repeated-measures ANOVA. This was essentially mean growth within each of the 3 years of 1999, 2000, and 2001, showing the contribution of each year's growth toward PAI. For example, CAI in 2001 was calculated by taking each tree's diameter measurement in 2001 (x_3) and subtracting each tree's diameter measurement in 2000 (x_2): $x_3 - x_2$. For the final step in figuring CAI, the value for each crop tree was then totaled to calculate the current year's mean growth. Epicormic branching values were also calculated by summing the mean number of epicormic branches by individual crop tree, block, plot, and branching category (< 1 foot or > 1 foot in length). Means were then compared by treatment and branching category using ANOVA and LSD pairwise comparisons.

RESULTS AND DISCUSSION

Crop Tree Diameter Growth Response

Among all trees, PAI of diameter growth in 1999 and 2000 was significantly greater in unthinned plots than in thinned plots (table 1). This was most likely due to the removal of trees in thinned plots because there were always less trees per acre in thinned plots than in unthinned plots. No difference in PAI of crop trees was noted until 2000 and

Table 1—PAI diameter growth of all trees and crop trees by treatment and year, where values in parentheses represent standard error, and means with the same letter are not significantly different

Trees	Treatments	1999 PAI	2000 PAI	2001 PAI
		inches		
All trees	Crown	0.10 (< 0.01) b	0.12 (0.01) b	0.15 (0.01)
	Low	0.12 (0.01) b	0.13 (0.01) b	0.13 (0.01)
	No	0.14 (0.01)a	0.14 (0.01) a	0.14 (0.01)
Pr > F		0.01	0.03	0.37
Crop trees	Crown	0.30 (0.02)	0.38 (0.02) a	0.44 (0.02) a
	Low	0.32 (0.03)	0.39 (0.05) a	0.38 (0.03) a
	No	0.29 (0.01)	0.30 (0.01) b	0.32 (0.01) b
Pr > F		0.13	0.06	0.01
All trees	Fertilized	0.12 (0.01)	0.13 (0.01)	0.14 (0.01)
	Unfertilized	0.12 (0.01)	0.13 (< 0.01)	0.14 (< 0.01)
Pr > F		0.67	0.48	0.26
Crop trees	Fertilized	0.28 (0.02)	0.34 (0.02)	0.38 (0.02)
	Unfertilized	0.33 (0.02)	0.37 (0.03)	0.38 (0.03)
Pr > F		0.13	0.33	0.78

PAI = periodic annual increment.

2001 when crop trees in thinned plots achieved significantly greater diameter growth than crop trees in unthinned plots. The growth of all trees preceding the growth of crop trees may be a case of stand level growth preceding individual tree level growth after thinning (Feduccia 1979, Feduccia and Mann 1976, Long 1985, Smith and Long 2001).

Furthermore, results of CAI showed that diameter growth of all trees in 1999 was better in unthinned plots than in thinned plots (table 2), which may be caused by greater basal area per acre in unthinned plots than in thinned plots. In 2000, CAI diameter growth of crop trees in thinned plots was significantly greater than CAI diameter growth of crop trees in unthinned plots. Most importantly, 2001 CAI diameter growth of crop trees in crown-thinned plots was greater than CAI diameter growth of crop trees in either low-thinned or unthinned plots. The diameter-growth responses to thinning found in this study are typical of many studies (Feduccia 1979; Graney 1987; Graney and Pope 1978; Johnson 1968; Johnson and McKnight 1969; Lambert 1957; Langsaeter 1941; Meadows and Goelz 1993, 1999, 2001; Schaertl and others 1997; Scott and others 2001; Stone 1977; Stringer and Wittwer 1985; Stringer and others 1988), but no study was found that specifically compared crown thinning and low thinning in bottomland hardwoods.

Table 2—CAI diameter growth of all trees and crop trees by treatment and year where values in parentheses represent standard error, and means with the same letter are not significantly different

Trees	Treatments	1999 CAI	2000 CAI	2001 CAI
		inches		
All trees	Crown	0.10 (< 0.01) b	0.15 (0.01)	0.20 (0.02)
	Low	0.12 (0.01) b	0.15 (0.01)	0.15 (0.02)
	No	0.14 (0.01)a	0.15 (0.01)	0.17 (0.02)
Pr > F		< 0.01	0.26	0.14
Crop trees	Crown	0.30 (0.02)	0.47 (0.02) a	0.55 (0.05) a
	Low	0.32 (0.03)	0.45 (0.06) a	0.38 (0.04) b
	No	0.29 (0.01)	0.31 (0.02) b	0.36 (0.03) b
Pr > F		0.13	0.02	< 0.01
All trees	Fertilized	0.12 (0.01)	0.15 (0.01)	0.18 (0.02)
	Unfertilized	0.12 (0.01)	0.15 (0.01)	0.16 (0.02)
Pr > F		0.67	0.26	0.47
Crop trees	Fertilized	0.28 (0.02)	0.40 (0.03)	0.45 (0.03)
	Unfertilized	0.33 (0.02)	0.42 (0.05)	0.42 (0.05)
Pr > F		0.13	0.67	0.43

CAI = current annual increment.

Epicormic Branching Response of Crop Trees

Mean number of all epicormic branches regardless of length only showed a difference in 2000 where crop trees in crown-thinned plots had more epicormic branches than crop trees in unthinned plots (table 3). This is most likely due to a greater amount of sunlight reaching tree boles in crown-thinned plots (Meadows 1995). In 2000, crop trees in fertilized plots also had significantly more epicormic branches than crop trees in unfertilized plots (table 3).

Mean number of epicormic branches according to branch length showed a difference in 2000 and 2001 where more epicormic branches >1 foot were found on crop trees in crown-thinned plots than in unthinned plots (table 4). Furthermore, in 1999, 2000, and 2001, more branches >1 foot occurred on crop trees in fertilized plots (table 4). In respect to thinning, these findings tend to contradict those of Meadows and Goelz (2001) who found that heavier thinning caused a minimal increase in epicormic branching among crop trees. They stated that retaining significant amounts of lower crown-class trees increased the risk of epicormic branching. However, findings in the present study upheld the findings of Chapin (1991) and Osmond and others (1987) who said that plants usually respond to an increase in stress by exhibiting a decrease in growth. Furthermore, Levitt (1980a, 1980b) defined biological stress as any change in environmental conditions that may reduce *or* adversely change a plant's growth or development. Levitt also distinguished between avoidance and tolerance of stress; during avoidance, the plant responds by attempting to reduce the impact of the stress factor (sometimes by growth), and during tolerance, the plant simply endures and survives the stress factor. Biological stress due to competition for nutrients and sunlight may be a cause of avoidance in the form of epicormic branching. Over all, there was a great decline in epicormic branches < 1 foot in 2000 and 2001 (table 4), which tends to indicate most new epicormic branches formed directly after thinning in crown-thinned and fertilized plots. Therefore, relatively few new branches have formed in 2000 and 2001, and those that formed after thinning are slowly dying back due to canopy closure.

Table 3—Mean number of all epicormic branches on crop trees by treatment and year, where values in parentheses represent standard error, and means with the same letter are not significantly different

Treatments	1999	2000	2001
Crown	24 (5)	16 (2)a	15 (2)
Low	22 (5)	11 (2)ab	11 (2)
No	17 (3)	8 (1)b	8 (1)
Pr > F	0.64	0.03	0.11
Fertilized	25 (4)	14 (2)a	13 (2)
Unfertilized	18 (2)	9 (1)b	10 (1)
Pr > F	0.64	0.02	0.11

CONCLUSIONS

Crop Tree Diameter Growth

A positive response in diameter growth of crop trees following both crown and low thinning was expected. This proved to be true when crop trees in thinned plots showed greater PAI diameter growth than unthinned plots in 2000 and 2001. Most notably, crown-thinned plots showed a greater CAI diameter-growth rate than both low-thinned and unthinned plots in 2001. A greater positive response in diameter growth of crop trees after crown thinning than after low thinning was also expected. This was only the case during 2001 measurements of CAI diameter growth. Furthermore, a greater positive response in diameter growth of crop trees in thinned and fertilized plots than in plots thinned alone was also expected. However, there was no diameter-growth response of crop trees due to fertilization treatment, which may be due to the current fertility of the soil. Under conditions of high mineral nutrient availability in soils, plants have a low potential to absorb mineral nutrients; therefore, nutrient demand by the plant has more effect on nutrient uptake than nutrient availability in the soil (Clarkson 1985). In other words, the crop trees in the present study could have already had enough nutrients when the fertilizer was applied.

Table 4—Mean number of epicormic branches on crop trees by treatment, year, and branch length, where values in parentheses represent standard error, and means with the same letter are not significantly different

Treatments	1999 < 1 foot	1999 > 1 foot	2000 < 1 foot	2000 > 1 foot	2001 < 1 foot	2001 > 1 foot
Crown	13 (3)	11 (3)	2 (<1)	14 (2) a	2 (<1)	13 (2) a
Low	14 (4)	9 (2)	2 (<1)	9 (1) ab	2 (<1)	9 (1) ab
No	12 (2)	6 (1)	2 (<1)	7 (1) b	2 (<1)	6 (1) b
Pr > F	0.68	0.12	0.15	0.01	0.52	0.02
Fertilized	14 (3)	11 (2) a	2 (<1)	12 (2) a	2 (<1)	12 (2) a
Unfertilized	11 (2)	6 (1) b	2 (<1)	8 (1) b	2 (<1)	7 (<1) b
Pr > F	0.68	0.05	0.15	0.02	0.26	0.03

Epicormic Branching

Thinning and fertilization were expected to decrease the occurrence of epicormic branching on tree boles, but drawing conclusions regarding epicormic branching measurements was difficult due to the absence of pretreatment measurements. However, data from second-and third-year results suggested a need for further research in this area. Crop trees in crown-thinned plots showed a significantly greater number of epicormic branches > 1 foot in 2000 and 2001. Furthermore, crop trees in fertilized plots also showed a significantly greater number of epicormic branches > 1 foot in 1999, 2000, and 2001 measurements. However, there was a great decline in epicormic branches < 1 foot in 2000 and 2001, which indicated most new epicormic branches formed directly after thinning. There was also a decline in total number of epicormic branches between 1999 and 2000, which indicated that branches formed after thinning have begun to die.

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