FIRST THROUGH FOURTH GROWING SEASON RESPONSES OF PLANTED LOBLOLLY PINE TO THINNING IN THE WESTERN GULF REGION

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Abstract—Thinning is commonly used in managing loblolly pine (*Pinus taeda* L.) plantations in the Western Gulf Region. While long-term loblolly pine growth responses to thinning have been well documented, understanding of the response in the first couple of years after thinning is limited. Data were collected for a loblolly pine thinning study from 16 sites across east Texas and western Louisiana over the first four growing seasons following thinning. Three thinning intensities, with residual stockings of 150, 225, and 300 trees per acre after thinning, and an un-thinned control were implemented across a range of sites with varying edaphic conditions. Thinning was performed at a stand age of approximately 12 years by removing every fifth row and then thinning from below poor quality trees from remaining rows. Thinning responses were expressed in relative terms by calculating the difference between a treatment mean and the control mean and expressing it as a percentage of the control mean. Results showed that (1) growth responses in diameter at breast height (d.b.h.) were positive at all thinning intensities, and the responses were stronger for the heavier thinning intensities and increased with year after thinning; (2) growth responses in total height were negligible, especially for heavier thinning intensities; and (3) tree size affected thinning responses both in d.b.h. and height growth, depending on the year post-thinning. Small trees (d.b.h. class of 6 inches) had the largest responses in d.b.h. growth but the responses of the medium (d.b.h. class of 8 inches) and large trees (d.b.h. class of 10 inches) increased with year until year 3. Responses in height growth of small trees were positive at year 1, in particular for heavier thinning, but became negligible after three growing seasons, while medium and large trees showed an opposite pattern, with the responses being small and negative initially but becoming positive, although small, at year 4. These results provide important information regarding early response of loblolly pine plantations to thinning in the Western Gulf Region.

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) plantations form a significant proportion of forest land in the Western Gulf Region and are especially important on intensively managed timberlands. In Louisiana in 2013, the growing stock of loblolly pine forests was nearly 9 billion cubic feet (Oswalt 2016). In east Texas, forest lands occupy about 12.1 million acres, of which, 2.9 million acres (24 percent) are classified as pine plantations, with most being composed of loblolly pine (Miles 2013). Due to the economic importance and large annual harvest and reforestation area, extensive studies have examined improving plantation productivity via practicing various silvicultural treatments, including thinning (Fox and others 2007). Typically, loblolly pine plantations in the Western Gulf are first thinned at approximately age 12 (average range of 10 to 15 years), commonly using a combination of geometric and low/improvement thinning (for example, removing every fifth row for access and then removing undesirable trees in the remaining rows).

Loblolly pine, a shade-intolerant tree species, produces best diameter growth under full sun. By opening the canopy, thinning improves light, nutrient, and water availability to residual trees through the removal of less desirable competing trees. Long-term effects of thinning on loblolly pine plantations are well documented. Research indicates that effects of thinning on tree growth varies with thinning method (Baldwin and others 1989), site productivity, geographic region, and other factors (Amateis 2000). For example, thinning has a positive influence on diameter-at-breast-height (d.b.h.) growth. Thinning's impact on total height (THT) growth is small and even negative immediately after application but may became positive thereafter (Ginn and others 1991, Tasissa and Burkhart 1997). Other than intensity of thinning and elapsed time since thinning, other factors such as type of thinning, stand age at time of thinning and site environmental conditions may alter the response.

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The application of these findings to pine plantations in the Western Gulf Region should be used with caution since these studies (1) focused on the Southeastern United States, with few samples in plantations in the Western Gulf Region and (2) utilized a low thinning method, rather than a geometric/low combination regularly used by forest industry. Most reported studies have focused on long-term responses despite the fact that short-term responses are more relevant to common forest management practices. Forest industry standard practices rarely delay second thinning or regeneration harvests for more than 5-7 years after first thinning, thus short-term, rather than long-term, response may be most relevant to current operational forest managers. Understanding of early responses to thinning for loblolly pine, while important for pine plantation management, still is limited. To this end, the East Texas Pine Plantation Research Project initiated a thinning study on 16 sites in 2014. Data from the first 2 years after thinning of nine sites were reported (Grogan and others 2018). An update of Grogan and others (2018), including data from additional sites (16 sites in total) and results for 4 years after thinning, is presented here.

MATERIALS AND METHODS

Sixteen research sites were established between 2014 and 2016, including 11 on regenerated forest sites (cutover and site prepared) and 5 on old field sites (fig. 1). Distributed across east Texas and western Louisiana, sites were selected so that various site qualities were sampled. Initial stand stocking ranged from 550 to 605 trees per acre, which is typical for young pine plantations in this region. Stand averages at time of plot installation were 13.7 years of age (range: 12 to 15), site index of 72 feet at base age 25 years (range: 59 to 87 feet), 7.6 inches d.b.h. (range 4.0 to 13.6 inches), and total height (THT) of 47.9 feet (range: 12.0 to 69.0 feet).

Four 0.5-acre square plots were established at each site with each plot having comparable site index, basal area, and number of trees to minimize variation. One of four thinning treatment categories was randomly assigned to each plot: no thin (control); thin to 150 residual trees per acre (T150, heavily thinned), thin to 225 (T225, moderately thinned), or thin to 300 (T300, lightly thinned). Thinnings followed current operational practices, using a combination of geometric and low thinning techniques by removing every fifth row for access and then removing undesirable trees in the remaining rows to meet the thinning target density.

The individual tree d.b.h. (inches) and THT (feet) were recorded before and annually after thinning. A preliminary analysis showed no difference among plots within a plantation for both traits before thinning. Trees were further assigned into three d.b.h. classes based on pre-thinning d.b.h. values: DC6 (d.b.h. ≤ 6.9 inches), DC8 (7.0 ≤ d.b.h. ≤ 8.9 inches), and DC10 (d.b.h. ≥ 9 inches). Data were examined for errors and outliers removed. An analysis of variance was carried out to test thinning response using the following mixed model:

$$y_{ijklm} = \mu + P_i + S_{j(i)} + T_k + D_l + ST_{j(i)k} + SD_{j(i)k} + TD_{kl} + \varepsilon_{ijklm} \quad (1)$$

where

y_{ijklm} is the d.b.h. or THT value of the m^{th} tree belonging to the l^{th} d.b.h. class and growing at the k^{th} thinning treatment plot of the j^{th} site and i^{th} plantation type,
P_i is the i^{th} plantation type effect,
$S_{j(i)}$ is the j^{th} site (within the i^{th} plantation type) effect,
T_k is the k^{th} thinning treatment effect,
D_l is the effect of the l^{th} d.b.h. class,
$ST_{j(i)k}$, $SD_{j(i)k}$, and TD_{kl} were interactions between site and thinning, between site and d.b.h. class, and between thinning and d.b.h. class, respectively, and
ε_{ijklm} is a random error with a mean of 0 and a variance σ^2.

Plantation type (cutover versus old field), thinning treatment, d.b.h. class, and their interactions were treated as fixed while site (within a plantation type) and its related interactions, $ST_{j(i)k}$ and $SD_{j(i)k}$, were treated as random so that results can be applied to the region. Other possible interactions were dropped as their effects were not significant. Note that a significant response refers to $\alpha = 0.05$ unless otherwise stated. Where significant treatment effects were observed, treatment least-square means were calculated. Thinning response (relative difference, RD) was calculated as the difference between the treatment and the control means, and then expressed as the percentage of the control:

$$RD = \frac{\text{Mean of a treatment} - \text{Mean of Control}}{\text{Mean of Control}} \times 100 \quad (2)$$

A positive RD suggests a positive response and an increase in growth from thinning relative to the un-thinned control.

RESULTS

Responses in Diameter Growth

Site effects were not significant, explaining less than 1 percent of the total variation for d.b.h. growth for each year after thinning (YAT) other than the second year, of which 10.9 percent of the variation was accounted for by site. Effects of site and thinning treatment interactions were small, explaining less than 4 percent of the total variation each YAT. Site and d.b.h. class interaction was important for 1 and 2 YAT, accounting for 17.9 percent and 11.5 percent of the variation, respectively, but became less important at 3 and 4 YAT.

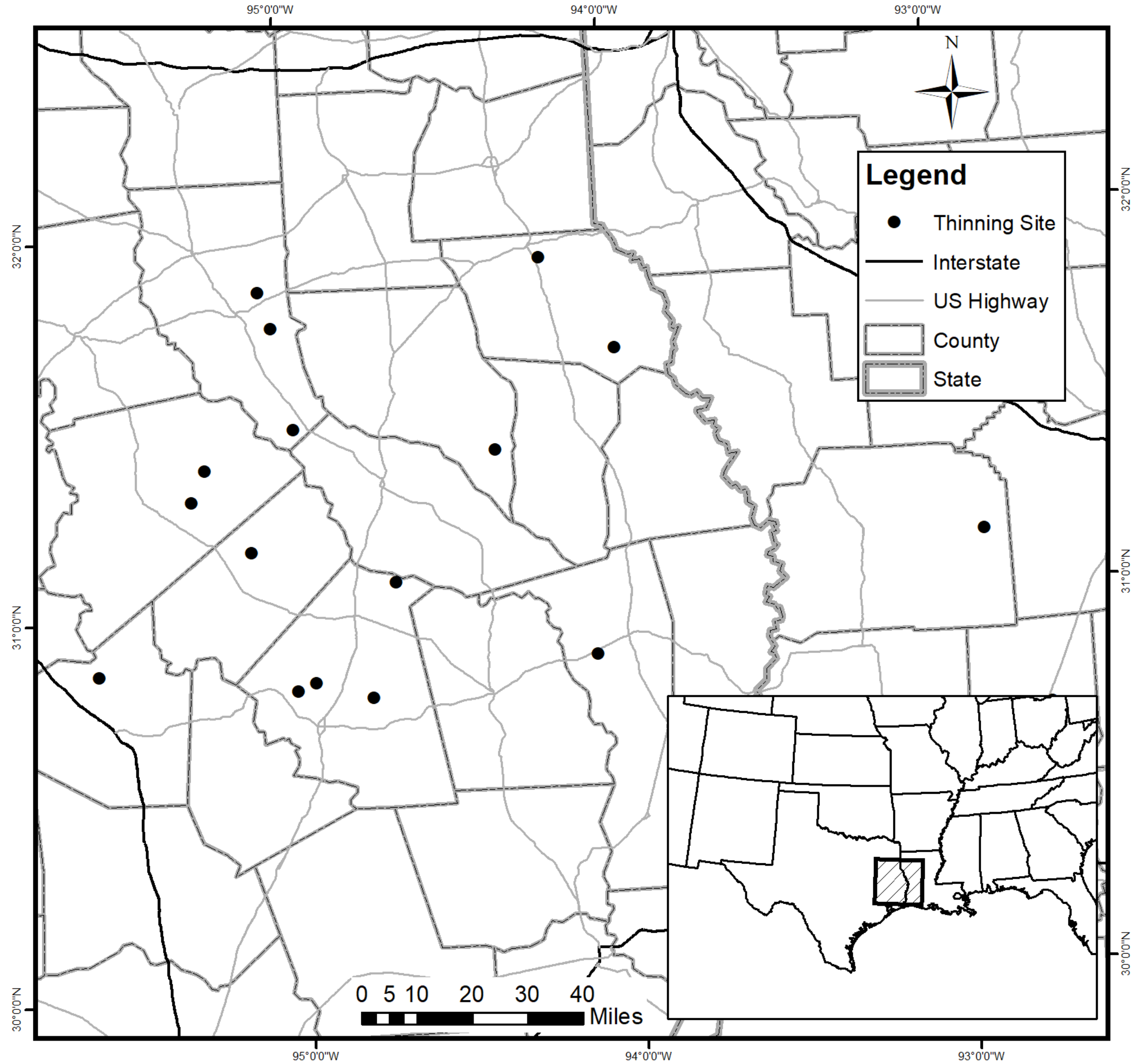

Figure 1—Locations of sites of the East Texas Pine Plantation Research Project loblolly pine thinning study.

Thinning enhanced d.b.h. growth significantly (table 1), more so in the more heavily thinned plots (fig. 2). The RD for each thinning treatment increased each of the first three YAT, yet 3 and 4 YAT were similar (fig. 2). For example, the T150 resulted a RD of 13 percent 1 YAT and increased to over 18 percent at 3 and 4 YAT. Multiple comparisons using the Tukey test showed (1) thinning treatments resulted in significant larger d.b.h. than the Control other than for T300. T300 had significant larger d.b.h. than the control at 1 YAT, but differences became insignificant 2 YAT; (2) d.b.h. differences among three thinning treatments varied with year, differences were significant only between T150 and T300 at 1 YAT but became significant between T150 and T225 2 YAT and among all treatments 3 YAT. At the fourth YAT, however, the thinning effects reduced, remaining significant only between T150 and T300.

Effect of plantation type on d.b.h. growth was significant. While trees on old fields grew faster than those on cutover sites on average, greater thinning responses on cutover sites than on old field sites were observed (fig. 3). This was particularly true for heavier thinning and at 3 and 4 YAT. Plantation type interaction with thinning treatment was not significant.

Diameter class influenced thinning response significantly (fig. 4). Under all intensities, smaller trees had greater, positive relative responses at each YAT. The RDs were comparable across 4 years for DC6, but increased from 1 to 3 YAT and then stabilized for those of DC8

Table 1—Average diameter at breast height by thinning treatment and year post-thinning

Thinning treatment	Year 1	Year 2	Year 3	Year 4
T150	9.15 a	9.68 a	10.00 a	10.62 a
T225	8.77 ab	9.20 b	9.37 b	10.01 ab
T300	8.24 b	8.62 bc	8.79 c	9.34 bc
Control	8.12 c	8.43 c	8.41 c	8.98 c

T150, T225, and T300: 150, 225 and 300 residual trees per acre after thinning; unthinned plots used as control.

Means within a column not followed by a common letter differ at α = 0.05 level.

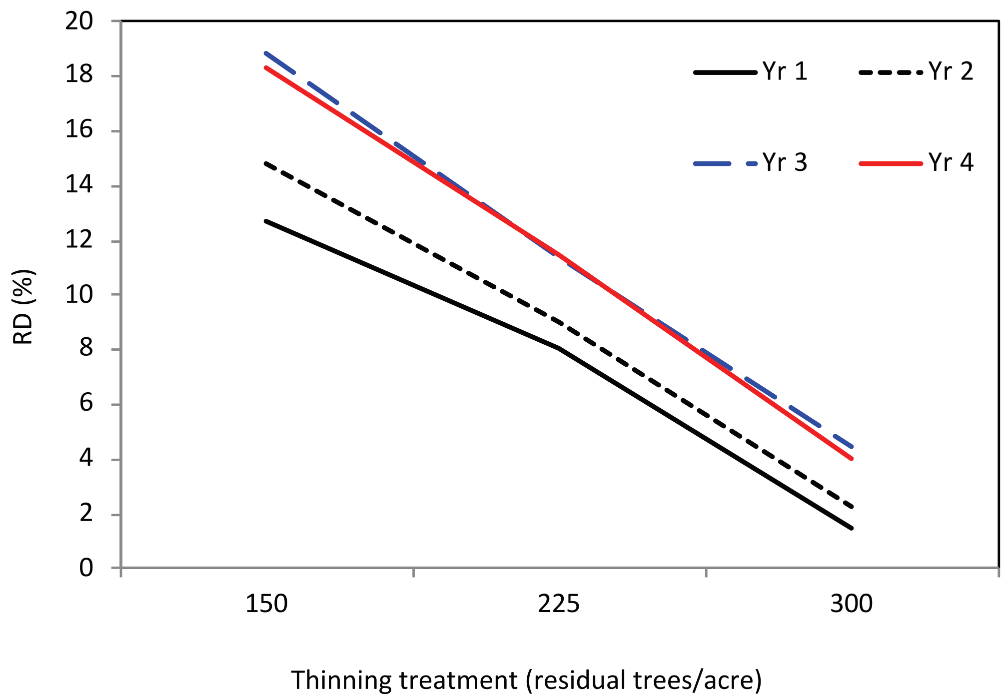

Figure 2—Relative differences (RD in percent) in d.b.h. growth for the thinning treatments compared to unthinned control one (Yr 1), two (Yr 2), three (Yr 3), and four (Yr 4) growing seasons after thinning.

and DC10. The only exceptions were the combination of T300 and DC10, with RD being negligible or even negative for the first 3 YAT, then becoming positive at 4 YAT. Thinning treatment and d.b.h. class interaction was significant for the first and second YAT, but not significant for the third and fourth YAT.

Responses in Height Growth

Effects of plantation type and thinning treatment on THT growth were statistically non-significant (data not shown). During the first 4 years post-thinning, T150 and T225 had positive RDs, while T300 showed negligible or negative responses. Diameter class, influenced THT growth significantly, depending on the year post-thinning (fig. 5). Trees of DC6 responded positively to thinning and showed a declining response with year post-thinning. DC8 and DC10 response was negative, similar among thinning treatments, and improved gradually with year.

DISCUSSION

Effects of thinning on d.b.h. growth were evident after one growing season post-thinning (table 1), supporting the previous findings of loblolly pine thinning studies in the Western Gulf Region (Coble and Grogan 2016) and other Southern United States regions (Pukkala and others 1998, Tasissa and Burkhart 1997). Some other studies reported different results; Ginn and others (1991) and Peterson and others (1997) found that when loblolly pine stands are thinned, time elapsed before the effects were evident (d.b.h. was not significantly greater in thinned stands until 4 years after thinning). However,

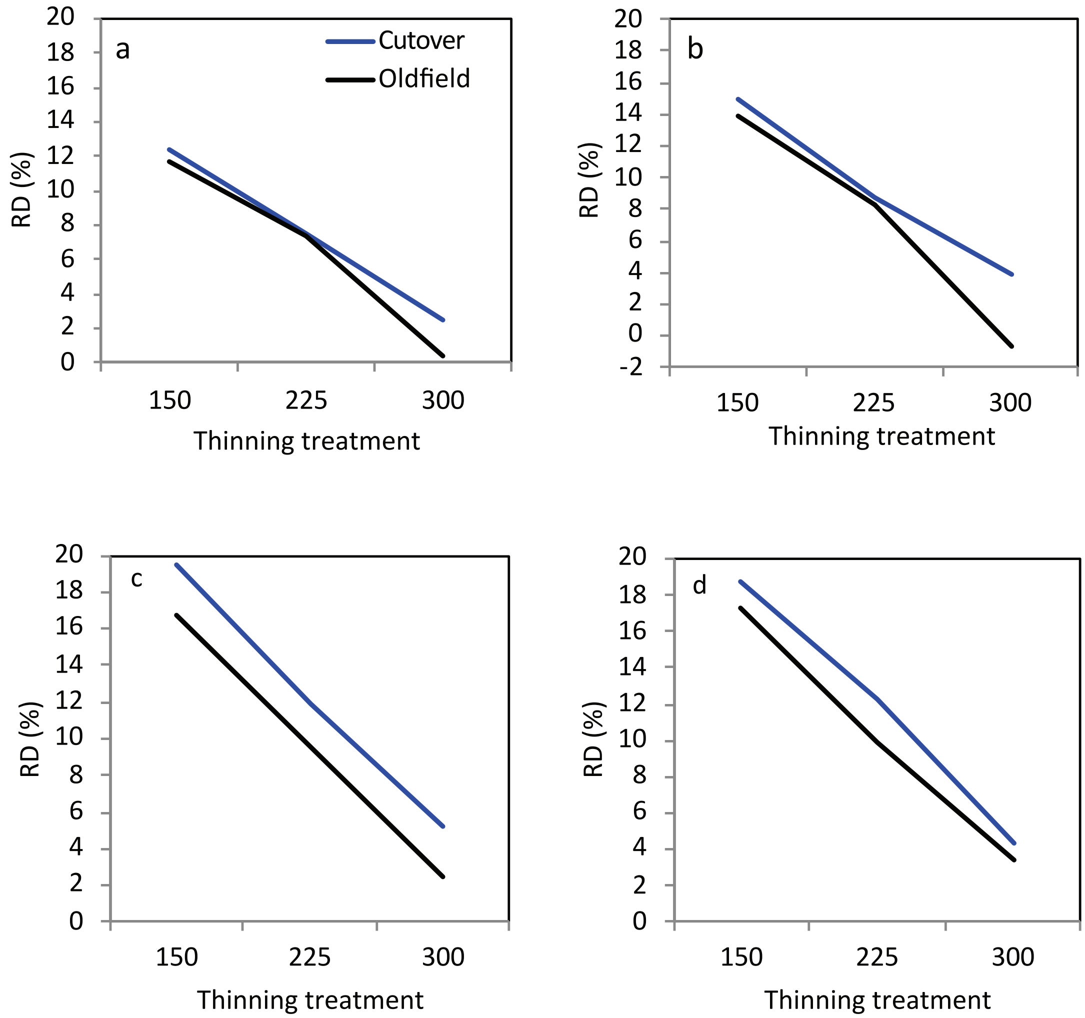

Figure 3—Effects of plantation type on d.b.h. growth responses to thinning (a) 1, (b) 2, (c) 3, and (d) 4 years after thinning. Relative difference (RD) is percent difference from the control.

some other studies reported similar results to this study. Greater d.b.h. growth following thinning for the heavier thinnings (fig. 2; table 1) and temporal patterns of increased response over time were observed in other loblolly pine studies (Moschler and others 1989, Pienaar and Rheney 1995, Tasissa and Burkhart 1997). Clearly, thinning improves availability in light, nutrient and/or water, resulting in an increase in d.b.h. growth over time until site resources again become limited (crown closure) at which time thinning effects decline.

Response of various size (d.b.h.) trees to thinning is of great interest to forest managers and growth-and-yield modelers (Burkhart and Tome 2012). Over the 4-year post thinning period, small trees (DC6) consistently responded more rapidly and strongly than the medium-sized (DC8) and large trees (DC10) (fig. 4), suggesting small trees may utilize free growing space more efficiently and create more photosynthate for growth, at least for the first 4 years post-thinning. Responses of larger trees (DC8 and DC10) were positive and were improved with year after thinning (fig. 4). The exception was T300, of which the responses of trees of DC8 and DC10 were negligible or even negative at the first and second years post-thinning, although became positive thereafter. Overall, trees responded positively in d.b.h. growth despite their size, clearly small trees benefit immediately and more after thinning than large trees. How the growth of individual trees of different sizes within a stand respond to thinning has rarely been studied on loblolly pine, but other species show contradictory results (Eriksson 1987, Hynynen 1995), with some being consistent with results reported here (Makinen and Isomaki 2004).

While radial growth is markedly responsive to thinning, height growth is statistically unaffected (Ginn and others 1991). Various theories have been proposed to explain the contrasting outcome between height growth and radial growth from thinning. After a thinning, a remaining tree first must improve its carbohydrate balance through increases in crown diameter and leaf

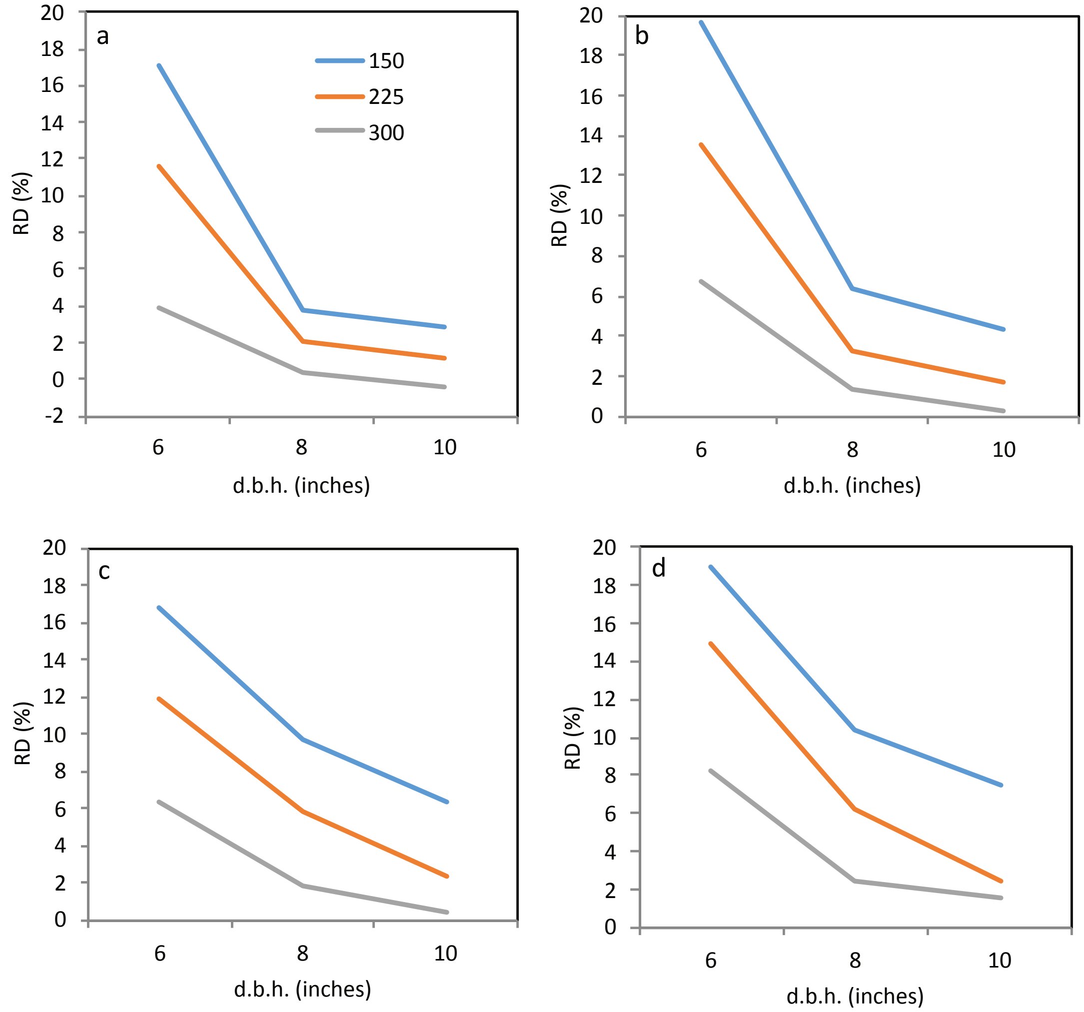

Figure 4—Initial tree d.b.h. effect on d.b.h. growth response to thinning (a) 1, (b) 2, (c) 3, and (d) 4 years after thinning. Relative difference (RD) is percent difference from the control.

area before it increases its volume growth, which often is at the expense of height growth, resulting in decreases in height growth during the first 2 years after thinning (Haywood 1994). Thinning response may also reflect a tradeoff between growing space improvement and thinning shock of a stand after thinning (Harrington and Reukema 1983). These results support both inferences generally, showing negligible increase or decrease in THT growth in all tested thinning intensities over the 4 years post-thinning. In the long term, trees on thinned plots may become comparable in height, or even taller, than those on unthinned counterparts (Brooks and Baily 1992). Despite weak responses overall, THT growth response varied with tree size, depending on the year post-thinning (fig. 5). The small-sized trees had an immediate positive response which subsided with year, while responses of large trees were negative initially but increased slowly with year. After four growing seasons, the RDs in height growth were mostly negative for trees of DC6 and DC8 but were all positive for trees of DC10. Although suppressed trees could react more rapidly and strongly (in relative terms) to thinning initially than large trees, the decline in their growth is accordingly more sudden and faster.

CONCLUSIONS

This study followed operational thinning protocol (i.e., method and stand age at thinning) typical for the region and sampled diversified environments across the region, and therefore the scientific implications derived from this study should reflect thinning responses of operationally thinned plantations in the region. Our results indicated that loblolly pine positively responded in d.b.h. growth immediately after thinning and this response became more evident with increasing year until 3 YAT. Trees responded more strongly to heavier thinning in d.b.h. growth. Thinning effects on height growth were basically negligible, regardless of thinning intensity. Results also showed that initial tree size could substantially affect tree growth response to thinning. The study will be monitored and measured in the future, and additional conclusions may be made when more data become available.

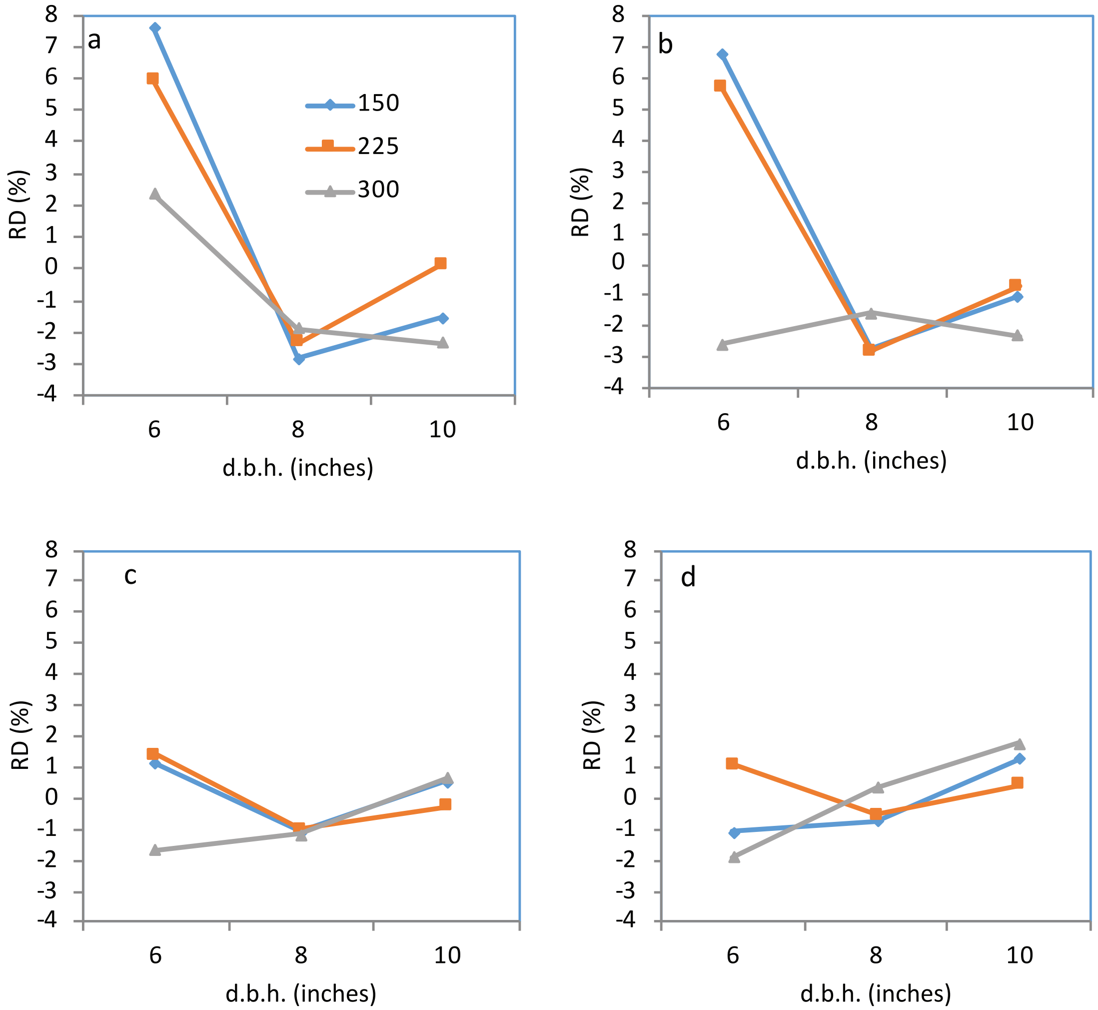

Figure 5—Initial tree d.b.h. effect on total height growth response to thinning (a) 1, (b) 2, (c) 3, and (d) 4 years after thinning. Relative difference (RD) is percent difference from the control.

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